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Robert S Kerr Environmental Research Lab, Ada, OK

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Chemical and Microbiological Implications

(Volume I Chemical Implications)

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16. ABSTRACT

The city of San Angelo, Texas, has used sewage effluent which has undergone primary treatment for irrigation of the same 259-hectare sewage farm since 1958. The impact of 18 years of sewage effluent irrigation on the soil and water quality was studied from 1975 to 1977. The volume of sewage arriving at the sewage treatment plant ranged from 0.219 to 0.351 m^3/sec. and contributed from 3.4 to 31.2 percent of the total flow of the bordering Concho River in 1976. The fate of applied nitrogen, phosphorus, and selected heavy metals in the soil-water-plant ecosystem were examined. There was evidence of some NO_3-N accumulation in the soil profile and in the Concho River while no accumulation of NH_4^+-N was found in the soil profiles. Some organic nitrogen accumulated at the soil surface, but after 18 years of operation there was a net loss of total nitrogen in the soil profile. Phosphorus accumulated in the soil profile to depths of 200 cm along with a slight build-up of certain heavy metals in the surface soils. Deep wells appeared to be uncontaminated by the sewage farm operation.

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SEWAGE DISPOSAL ON AGRICULTURAL SOILS: CHEMICAL AND MICROBIOLOGICAL IMPLICATIONS

VOLUME I

CHEMICAL IMPLICATIONS

by

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

William C. Galegar

William C. Galegar
Director
Robert S. Kerr Environmental Research Laboratory

ABSTRACT

The city of San Angelo, Texas has used sewage effluent, which has undergone primary treatment, for irrigation of the same agricultural land since 1958. The impact of 18 years of sewage effluent irrigation on the soil and water quality of the 259 hectare sewage farm was studied from 1975 to 1977. The volume of sewage arriving at the sewage treatment plant ranged from 0.219 to 0.351 m^3/sec. In 1976, sewage effluent contributed from 3.4 to 31.2 percent of the total flow of the Concho River, which borders the sewage farm.

The fate of applied nitrogen, phosphorus, and selected heavy metals in the soil-water-plant ecosystem was examined. Nitrogen and phosphorus were being applied to the farm in large amounts. The average concentrations of nitrogen and phosphorus in lagoon No. 4 effluent were 22.2 µg N/ml and 9.83 µg p/ml, respectively. The concentration of Zn, Cu, Ni, Cd, Cr and Pb in the incoming sewage effluent was low.

There was evidence of some NO_3^--N accumulation in the soil profiles and in the Concho River. No accumulation of NH_4^+-N was found in the soil profiles. Some organic nitrogen accumulated at the surface of the soil. After 18 years of continuous irrigation with sewage wastewater there was a net loss of total nitrogen in the soil profile. Phosphorus accumulated in the soil profile. It is apparent that most of the phosphorus was retained in the upper 200 cm of soil. Significant increases in water soluble phosphorus in the upper 200 cm of soil indicates a buildup of soluble forms to that depth. There was a slight accumulation of certain heavy metals in the surface of the soils. Generally, heavy metal contamination is not a serious problem on the sewage farm.

Water from deep wells located on the sewage farm had a nutrient composition similar to wells located in the surrounding area of Tom Green County. The results indicate that land disposal of municipal sewage effluent combined with a forage and cattle production system can be considered a practical long-term treatment scheme.

This report was submitted in fulfillment of Grant No. R803281 by Texas A&M University under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period April 28, 1975, to June 27, 1977, and work was completed as of June 27, 1977.

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The cooperation of those landowners in Tom Green County who allowed us to periodically sample their domestic wells is appreciated.

SECTION 1

INTRODUCTION

Man and his environment must be protected from pollution caused by his products and wastes. Disposal of human waste has been one of the most interesting and persistent problems since the beginning of civilization. Recently, the practice of land disposal has received much attention as a modern technique for advanced wastewater treatment. Public Law 92-500 enacted on October 18, 1972, requires increased treatment of municipal wastewater to reduce water pollution. By 1977 all publicly owned wastewater treatment plants are required to meet the secondary treatment effluent standard.

The city of San Angelo, Texas, has been using the same agricultural land for disposal of municipal wastewater since 1958. A primary treatment involving settling and screening of solids has been used before application of the sewage wastewater to a 259 hectare farm. The wastewater has never been chlorinated or intentionally disinfected. Much of the applied wastewater reaches the Concho River, which borders the sewage farm, by underground seepage. Direct surface runoff of sewage wastewater from the farm does not occur because the land has been terraced and borders built to retain the wastewater. The soils on the farm are rather shallow clays or clay loams and have been used for forage and cattle production. Some hay is removed from the land and sold. Much of the land has been planted to Coastal bermudagrass and is grazed by cattle.

Land has a great capacity for receiving and decomposing human wastes. The soil-water-plant system plays an important role in the renovation of wastewater. To date, one of the unknown factors in land disposal is the potential contamination and accumulation of wastes in the field, especially the long-term effect. The objectives of this study are as follows:

1. Determine the fate of applied nitrogen, phosphorus, and selected heavy metals in the soil-water-plant ecosystem.

2. Compare the concentrations of nitrogen, phosphorus, and heavy metals in soil, water, and plant samples taken from the sewage farm with those taken from adjacent control areas.

3. Measure the chemical characteristics of sewage farm surface soils and evaluate their relationship to the concentrations of nitrogen, phosphorus, and heavy metals in the soils.

4. Make recommendations for the disposal of sewage wastewater on the land in view of the effect of nitrogen, phosphorus, and heavy metals on the environmental quality.

SECTION 2

SUMMARY AND CONCLUSIONS

The 259 hectare sewage farm had been in operation for 18 years and received all the sewage from the city of San Angelo at the time this study was conducted. San Angelo is located in a semi-arid region of Texas and receives an average of 53 cm of rainfall per year. The average annual temperature is 19.0°C. The population in 1975 was 67,000.

Gross yields of forage was much higher than on adjacent areas where irrigation was not practiced. Stocking rate of cattle on the sewage farm was 2.7 head/ha in 1976. This was twenty times higher than the stocking rate of surrounding rangeland. In addition, 21,600 bales of hay were sold. Total gross income from the farm in 1976 was $57,576.

Daily flow of sewage to the farm ranged from 0.22 to 0.35 m^3/sec. The effluent was separated from solids in a settling tank. It was then either pumped directly to the land or passed through one to three storage lagoons before being distributed to various parts of the farm. Water from the lagoons was distributed through a gravity flow underground pipe system where it was used for irrigation. Surface irrigation, using bordered terraces, was used to prevent surface runoff and provide even distribution of water.

Water moved vertically through the soil until it reached relatively impermeable soil layers. The water then moved laterally and surfaced as seepage creeks or seeps which eventually flowed into the Concho River which borders the sewage farm. Seeps along the bank of the Concho River were observed in the soil profile above the Permian red clay beds.

The San Angelo sewage farm contributed from 3.7 to 31 percent of the total flow of the Concho River during 1976. The average flow contribution was 0.14 m^3/sec (12.5 percent).

Nitrogen and phosphorus in the effluent were being applied to the farm in large amounts. The concentration of N in the water (from lagoon no. 4) was 29.8 µg N/ml, primarily as NH_4^+ and organic N. The concentration of phosphorus in the irrigation water was 18.45 µg P/ml and was in the ortho- or organic phosphate forms.

Nitrogen present in the seepage waters was in the NO_3^- form. Mean NO_3^--N concentrations in three seepage creeks flowing into the Concho River ranged from 10 to 21 µg/ml.

There was no accumulation of NH_4^+-N or NO_2^--N in the soil profiles. Some organic N accumulated at the surface of the soil, and there was evidence of NO_3^--N accumulation in the profiles of the Angelo and Mereta soils. Oxidation of NH_4^+ to NO_3^- must have been very rapid to prevent appearance of NO_2^-. After 18 years of continuous irrigation with sewage effluent there was a net loss of total N in the soil profile.

Phosphorus accumulated in the soil profile. There was a significant increase in water soluble phosphorus in the upper 200 cm of soil. Movement of phosphorus into well waters and seepage creeks 2 and 3 was 0.06 µg P/ml. The concentration of phosphorus in seepage creek no. 1, which runs through the farm, reached a high of 3.80 µg P/ml during the month of June. The average concentration of P in seepage creek 1 was 0.79 µg P/ml. The average concentration of P in the Concho River below the sewage farm was 0.078 µg/ml.

Application of fertilizer nitrogen and phosphorus to Coastal bermudagrass did not increase production. The test was conducted on a replicated field plot experiment on the Angelo soil series. The quantity of nitrogen and phosphorus in the irrigation water was adequate for maximum production.

Heavy metal contamination was not a problem on the San Angelo sewage farm. There appeared to be some accumulation of Cd, Cr, Cu, Pb, and Zn in the surface horizons of the Mereta soil which was located adjacent to the effluent lagoons. There was also a light accumulation of Pb in the surface of the Angelo soil. Consistently higher concentrations of Cr throughout the Rioconcho profile was probably due to natural variation between sample sites. In general, the heavy metal concentration of the sewage was low because of the general lack of industry in the San Angelo area that would contribute heavy metals.

Soils nearest to the sewage effluent lagoons have received significantly more effluent than those located some further distance away. The total soil content of phosphorus, nitrogen, and heavy metals were considerably higher in Mereta and Angelo soils.

Water from wells located on the sewage farm had a nutrient composition similar to wells located in Tom Green County. The average nitrate concentration in domestic deep wells at the sewage farm and surrounding Tom Green County was 15.7 and 22.0 µg NO_3^--N/ml, respectively. The average nitrate concentration in shallow groundwater wells at the sewage farm was 5.8 µg NO_3^--N/ml. More than 60 percent of the well water samples analyzed had nitrate concentrations greater than 10 µg NO_3^--N/ml. High NO_3^--N concentrations, exceeding 50 ppm in some wells, should be considered a serious problem. The unusually high NO_3^- concentrations appear to be a result of natural distribution and contamination of the aquifer and not due to the sewage farm.

The primary contributions to the Concho River from the San Angelo sewage farm appear to be an increased flow rate of the river and a slightly higher NO_3^--N concentration in the river below the sewage farm.

SECTION 3

RECOMMENDATIONS

Land disposal of municipal wastewater at San Angelo, Texas, combined with a forage crop and cattle production system, can be considered a practical long-term wastewater treatment scheme. Minimal alteration of the water quality of surrounding surface streams and groundwaters has occurred as a result of the sewage farm operation. Increased levels of NO_3^--N in the Concho River appear to be the primary concern and will warrant continued monitoring.

Based on the current daily volume of incoming sewage wastewater to the sewage plant and the present acreage of the sewage farm, it will be necessary in the near future to expand the sewage farm acreage to effectively dispose of the increasing volume of sewage wastewater. Disposal of wastewater over a larger acreage will also eliminate and/or reduce the chances of direct discharge of sewage wastewaters into surrounding surface streams. An expanded acreage would lower the annual loading rate of the soil and allow more recovery time between applications of sewage effluent. Lower annual loading rates of the soil would also extend the useful life of the farm as a sewage effluent disposal site.

Nitrogen and phosphorus inputs from sewage effluent are adequate to meet the nutritional requirements of the crops. Therefore, additional applications of these elements as fertilizer are not recommended. Chemical and/or biological processes which can reduce the high nitrate concentration in domestic deep wells at the sewage farm and surrounding Tom Green County should be considered since these waters are used as a domestic water supply.

Irrigation with wastewater effluent on the sewage farm for the past 18 years has significantly changed the concentrations of some of the chemical elements in the soils. Of those elements determined in this study, none were present in what would be considered as toxic amounts. However, as industry expands or the chemical composition of sewage effluent changes, further investigations and periodic monitoring of the site are recommended.

SECTION 4

GENERAL PROJECT CHARACTERISTICS

TOPOGRAPHY

Hilly areas, plains, and river valleys are the three types of topography present in Tom Green County where San Angelo, Texas is the county seat (Willis, 1954). Hilly remnants of a northward extension of the Edwards Plateau cover much of the northern, western, and southern parts of the county. Plains lie east of San Angelo from the northern boundary of the county southward to the base of the hills of the Edwards Plateau. That portion of the plains south of the Concho River is known as Lipan Flat. River valley flats lie along the Concho River and its tributaries--the North, Middle, and South Concho Rivers--which join before reaching the San Angelo sewage farm land 8 km east of the city limits on Farm Road 380. The highest point in the county is near the southwest corner, located 40 km southwest of the sewage farm where the altitude is approximately 778 m. The lowest point is the bed of the Concho River at the Tom Green-Concho County line, 19 km down river from the sewage farm where the altitude is approximately 503 m. The location of the San Angelo area is shown in Figure 1.

The San Angelo sewage farm is located on the plains bordering the north bank of the Concho River. The land is slightly sloping from 0 to 3 percent southward toward the river or to a drainage creek in the northern area of the farm which flows into the Concho River east of the sewage farm.

Adjacent land to the west and north is cleared rangeland, typical of the arid region. The land on the eastern border of the sewage farm is cultivated in wheat and irrigated with water pumped from the river. This land gently slopes toward the river and has very productive soil. The private land on the river surrounded by the sewage farm is similar to the rangeland located west and north of the sewage farm, except for that portion that is productive river valley soil and is cultivated in grain sorghum and wheat.

The moderate annual rainfall, gently sloping terrain, and properly managed grasslands keep erosion in check on the lands adjacent to the sewage farm. Flooding is not a problem due to the three large reservoirs--Twin Buttes, O. C. Fisher, and Lake Nasworthy--which are located on the river and its main tributaries west of San Angelo.

Source: Adapted from Erwin Raisz, *Landforms of the United States*, 1957.

Figure 1. General topography and location of study site at San Angelo, Texas.

Rangeland adjacent to the sewage farm has been chained and pushed with bulldozers for brush control and optimum native forage production. Cultivated land was root plowed and broken from mechanized row cropping.

The land on the San Angelo sewage farm, which was initially row cropped, has now been established in permanent pasture except for three cultivated fields which are used to produce forage sorghum or small grains for grazing and haying. Due to water disposal requirements which keep the soil very wet, the grass fields are seldom disturbed by farming equipment. The cultivated fields are plowed in early spring and fall for seedbed preparation prior to planting.

GEOLOGY

Rock formations exposed in Tom Green County are of sedimentary origin. The oldest of these belong to the Permian system and are exposed along the Concho River (Barnes 1974). The regional dip of the Permian rocks is westward at a rate of approximately 9.5 m to the km. The hilly remnants of the Edwards Plateau are composed of rocks in the Cretaceous system which dip southeastward at a very low angle. Older Quaternary alluvium (the Leona Formation) covers the Permian rocks in most of the plains area. Younger Quaternary alluvium is present in the stream valleys. A cross section of the geologic strata of Tom Green County is presented in Figure 2.

The land in the sewage farm area is located on the Leona formation which is typified by the conglomerate along the Concho River. The conglomerate is classified as Pleistocene and Pleistocene alluvium and is derived from rocks of the Edwards Plateau. The alluvium was deposited on the eroded surfaces of the Permian rocks over about 1036 square km in the plains areas of the county. The thickness of the alluvium ranges from 1 m to about 38 m. The alluvium is composed of discontinuous beds of poorly sorted, rounded to subangular gravel, conglomerate, sand, silty clay, and caliche. The upper 20 m of soil is predominately clay and clay loam. The particles of gravel are composed of limestone and flint, some of which contain fragments of Cretaceous fossils. Rocks in the county which are older than those exposed are not known to contain potable water. Water wells in the county do not penetrate these older rocks. Most of the irrigation wells in the county draw water from the more permeable layers of gravel and creviced conglomerate.

GROUNDWATER

Groundwater in the area is derived strictly from precipitation on the land surface, except for the immediate sewage farm area and the Lipan Flat where irrigation has contributed to water tables. The non-precipitation contribution to groundwater in the sewage farm area is the municipal sewage effluent from the city of San Angelo which is used for irrigation and, in the Lipan flat, the water from the irrigation canal from Lake Nasworthy.

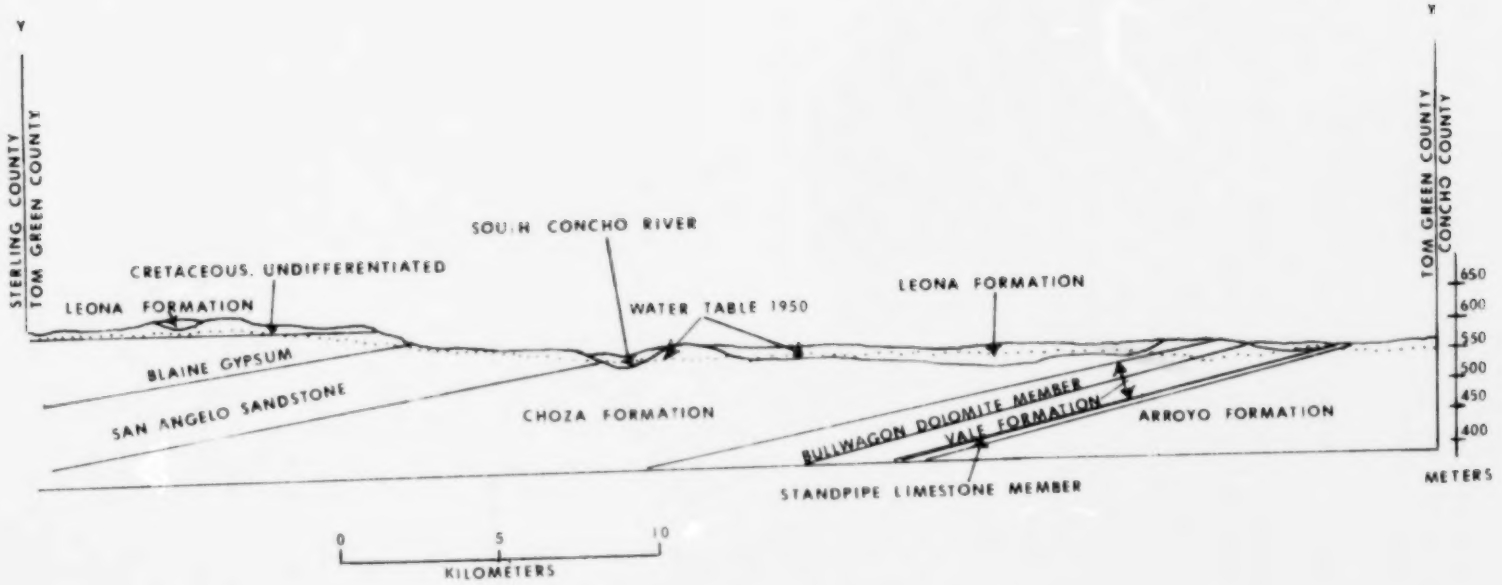


Figure 2. Cross section of the geologic strata of Tom Green County, Texas

The Texas Board of Water Engineers in cooperation with the U. S. Geological Survey have found that most water wells in the area are in the Leona formation and range to about 30.5 m in depth.

CITY POPULATION AND INDUSTRIAL INPUT

The city of San Angelo is a steadily growing community with a 1975 population estimated at 67,000. Daily sewage rates to the treatment plant are from 0.219 to 0.241 m^3/sec with a minimum flow of 0.153-0.175 and a maximum flow of 0.307 to 0.351 m^3/sec. Sewage inputs are predominately domestic. Industrial flow in 1977 accounted for 0.0162 m^3/sec according to the city water department. Major industries involve a creamery with the greatest input, 4 packing plants, 2 large commercial laundries, 1 bottling plant, and 2 foundaries which contribute recycled cooling water.

Population growth of the city of San Angelo from 1910 to 1975 is listed in Table 1.

TABLE 1. SAN ANGELO CITY POPULATION INCREASE WITH TIME

Year	Population
1910	10,321
1920	10,050
1930	25,308
1940	25,802
1950	52,093
1960	58,815
1970	63,884
1975[a]	67,000

[a]estimated

WASTEWATER TREATMENT FACILITIES

The sewage treatment plant of the city of San Angelo, Texas was designed for primary treatment by screening, sedimentation, skimming, and separate digestion of sludge. Digested sludge was to be mixed into settled sewage or placed on a designated area and plowed into soil by mechanized farm equipment. During this project a new sewage treatment plant was under construction and the original method of handling had to be altered. The method used during the time this project was underway was simply primary treatments of sewage and piping both solids and liquids to lagoon 1, lagoon 2, or occasionally flooding land directly with the primary treated sewage.

Presently the sewage plant handles 0.219 to 0.263 m^3/sec of incoming sewage. The sewage enters the plant by a 0.76 m diameter line. After

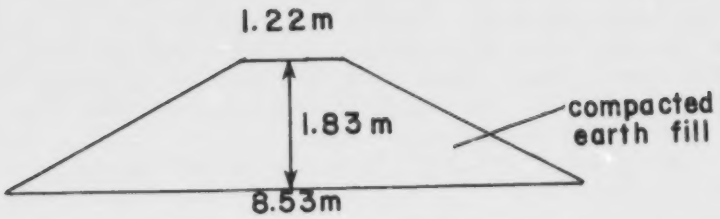
passing through a bar screen the sewage was lifted to a clarifier (18.3 m in diameter x 0.61 m deep) by alternating 0.372 and 0.456 m^3/sec electric pumps. Sometimes sediment from the clarifier was pumped into an adjacent 6.19 ha surface area sludge lagoon, and sewage effluent was pumped from the clarifier to the first of a series of three lagoons located at the opposite end of the farm. Other times both effluent and sludge were pumped into lagoon 1 or lagoon 2. The total surface area of the three lagoons was 17.68 ha. In these three lagoons the sewage was subjected to oxidation and further settling. Effluent overflowed from the second lagoon to the third lagoon and from the third lagoon to the fourth lagoon. Water for irrigation was used directly from each lagoon.

Irrigation was accomplished by distribution from underground mains into level borders of approximately 0.2 ha each. The borders were separated by levees not less than 0.25 m high, and each field had a perimeter levee on its lower side, built to a minimum height of 0.46 m, to insure that sewage effluent did not flow directly from the field to a water course. Specifications for the three types of levees present on the farm are shown in Figure 3.

VEGETATION ON FARM

There were approximately 259 ha of the sewage farm that received sewage effluent and were used for hay production and grazing. Coastal bermudagrass, Kentucky 31 fescue, and NK 37 bermudagrass were the forage grasses in the permanent pastures. There were approximately 127 ha of Coastal bermudagrass (Cynodon dactylon). The growing season at the sewage farm for Coastal bermudagrass is from March through September. Kentucky 31 fescue (cool season perennial) grew from November through June and there were approximately 40 ha of the farm in this grass. NK 37 is a hybrid bermudagrass variety of the Northrup King seed company. It is a warm season bermudagrass. There were approximately 77 ha of cultivated land on the sewage farm. A warm season annual forage sorghum was utilized for hay and grazing in the spring and summer. Following the last harvest of the forage sorghum in the early fall the cultivated land was plowed and planted in oats. The oats receive strong competition from rescuegrass (Bromus wildenowii), a cool season annual native, which was very prolific. Rescuegrass could be found growing anywhere on the farm by late winter, and if the bermudagrass sod was plowed in the fall, an excellent stand of rescuegrass occurred.

All the grasses on the sewage farm were utilized for hay. Hay fields were cut frequently and provided a primary source of income for the farm. Frequency of cutting depended on weather limitations, grazing intensities, and flooding frequency as dictated by sewage accumulations. In 1975 approximately 27,800 bales of hay were sold despite the yearly average grasing intensity of 2.08 head of cattle per ha. In 1976 approximately 21,600 bales of hay were sold during a grazing intensity of 2.69 head of cattle per ha. For native range the 508 mm rainfall average restricted stocking rates to one animal unit per 8 ha on good cleared range and to one animal unit per 20 ha on poor brushy range.



Typical section of holding pond levee

Border levee

Field perimeter levee

Figure 3. Cross sections of three different types of levees present on the San Angelo sewage farm.

Natural vegetation in the area is greatly dependent on grazing practices. Although very little native vegetation occurred on the farm, other than weeds such as pigweed (Amaranthus retroflexus), nightshade (Solanum sp.), or mesquite trees (Prosopis sp.), the immediate area surrounding the farm is inhabited by grasses, brush, and short trees. The predominant warm season grasses are sideoats grama (Bouteloua cutipendula), cane bluestem (Andropogon barbinodis), buffalo grass (Buchloe dactyloides), vine mesquite (Panicum obtusum), plains bristlegrass (Sterai leucopila), purple threeawn (Aristida purpurea), and other arid area species. The predominate cool season grasses are rescue grass (Bromus wildenosii), Canada wildrye (Elymus canadensis), and Texas wintergrass (Stopa leuotricha). Trees in the area are predominately mesquite (Prosopis juliflora) and are seldom over 6 meters tall.

ANIMAL POPULATION AND CROP PRODUCTION

Cattle are the only livestock grazed on the sewage farm. All animals are rotated from field to field to permit haying, flooding, planting, or any other operation and are not grazed specifically in any one field or combination of fields. All classes of cattle are grazed on the farm and grazing records are kept according to animal grazing days (AGD). One animal grazing day is defined as the presence of one cow, cow and calf, or a bull grazing on the sewage farm for one day. Yearling cattle are listed as cows in the farm records since they consume approximately the same amount of forage.

Approximately 259 ha of the farm are flood irrigated with sewage effluent, grazed, and hayed. The data in Tables 2 and 3 show livestock numbers on the farm for 1976 and 1976. The average number of cattle per month and the livestock grazing intensity (head/ha) are also shown.

Since 1976 was a wet year, it was not a good year for hay production because cut hay was rained on, and rainfall interrupted other forms of haying. The sewage farm may realize more income by intensifying haying operations and decreasing livestock numbers, especially during the warm season of the year when hay production is greatest. The gross income of sewage farm in 1975 and 1976 are shown in Table 4.

TABLE 2. CATTLE PRESENT ON THE SAN ANGELO CITY SEWAGE FARM IN 1975

Month	Animal Grazing Days				Head per Month
	Cows	Pairs	Bulls	Total	
Jan.	7863	1830	367	10060	335
Feb.	6120	1830	330	8280	276
Mar.	7452	1830	330	9612	320
Apr.	7500	1830	330	9660	322
May	12054	1740	180	13974	466
June	21146	1740	180	23066	769
July	19170	1740	120	21030	701
Aug.	21644	1740	150	23534	784
Sept.	20640	1740	150	22530	751
Oct.	17874	1140	150	19164	639
Nov.	17640	1140	150	18930	631
Dec.	13524	780	120	14424	481

Total 6475
Average head per month (1975) 540
Grazing intensity (head/ha) 2.08

TABLE 3. CATTLE PRESENT ON THE SAN ANGELO CITY SEWAGE FARM IN 1976

Month	Animal Grazing Days				Head Per Month
	Cows	Pairs	Bulls	Total	
Jan.	9210	780	120	10110	337
Feb.	12330	780	210	13320	444
Mar.	17220	780	210	18210	607
Apr.	34287	780	240	35307	1177
May	23640	780	180	24600	820
June	23640	780	180	24600	820
July	23640	780	180	24600	820
Aug.	22500	780	180	23460	782
Sept.	11570	780	180	16530	551
Oct.	21870	1050	180	23100	770
Nov.	20566	1050	150	21766	726
Dec.	15135	300	150	15585	520

Total 8374
Average head per month (1976) 698
Grazing intensity (head/ha) 2.69

TABLE 4. GROSS INCOME OF SAN ANGELO CITY SEWAGE FARM

Year	Item	Unit Price	Income
		$	$
1975	27,828 bales	1.50	41,742.00
	294,264 AGD*	0.10	29,426.40
		Total	71,168.70
1976	21,632 bales	1.50	32,448.00
	251,188 AGD	0.10	25,118.80
		Total	57,567.30

* AGD is animal grazing days.

SECTION 5

METHODS AND MATERIALS

HYDROLOGY AND METEOROLOGY

Water flow of three seepage creeks in the sewage farm was continuously monitored over a one year period by installation of weirs in conjunction with a water level recording device (Stevens type F recorder, model 68). A 90-degree V-notch weir was installed in seepage creek 1. A 60-degree V-notch was installed in seepage creeks 2 and 3. This weir design permitted accurate measurement over a wide range of water flow. Measurement of water flow of the Concho River was determined by the area-velocity method with a F583 Pygmy-type water current meter on the Concho River at sampling sites above and below the sewage farm. These measurements provided an estimate of water contribution of the sewage farm to the Concho River. Irrigation flow of sewage effluent to the fenced Coastal bermudagrass area was determined with a commercial type Badger magnetic drive irrigation meter. The location of weirs, Concho River sample sites, and the fenced plot area in relation to the effluent lagoons are shown in Figure 4.

A temperature recording device (Weathermeasure Corp. model T603, three point thermograph) was installed in the fenced Coastal bermudagrass area. Air temperature and soil temperatures at 10 cm and 40 cm depths were monitored hourly. Precipitation was recorded at the fenced plot area with a weighing rain gauge made by Belfort Instrument Company.

WATER ANALYSIS

Water Sampling Locations

Sewage Farm Locations--

The on-farm water sampling sites were located across the entire area. These locations were selected to permit monitoring of sewage effluent from the time it entered the treatment plant until it flowed into the Concho River adjacent to the sewage farm through seepage creeks. Ground water was sampled from shallow (1.5-9.1 m) wells and from deep (21.3-36.6 m) wells located within the sewage farm boundary (Table 5).

Non Sewage Farm Locations--

Water samples were collected from domestic wells in Tom Green County, Texas on an irregular basis. These sampling sites are located within a

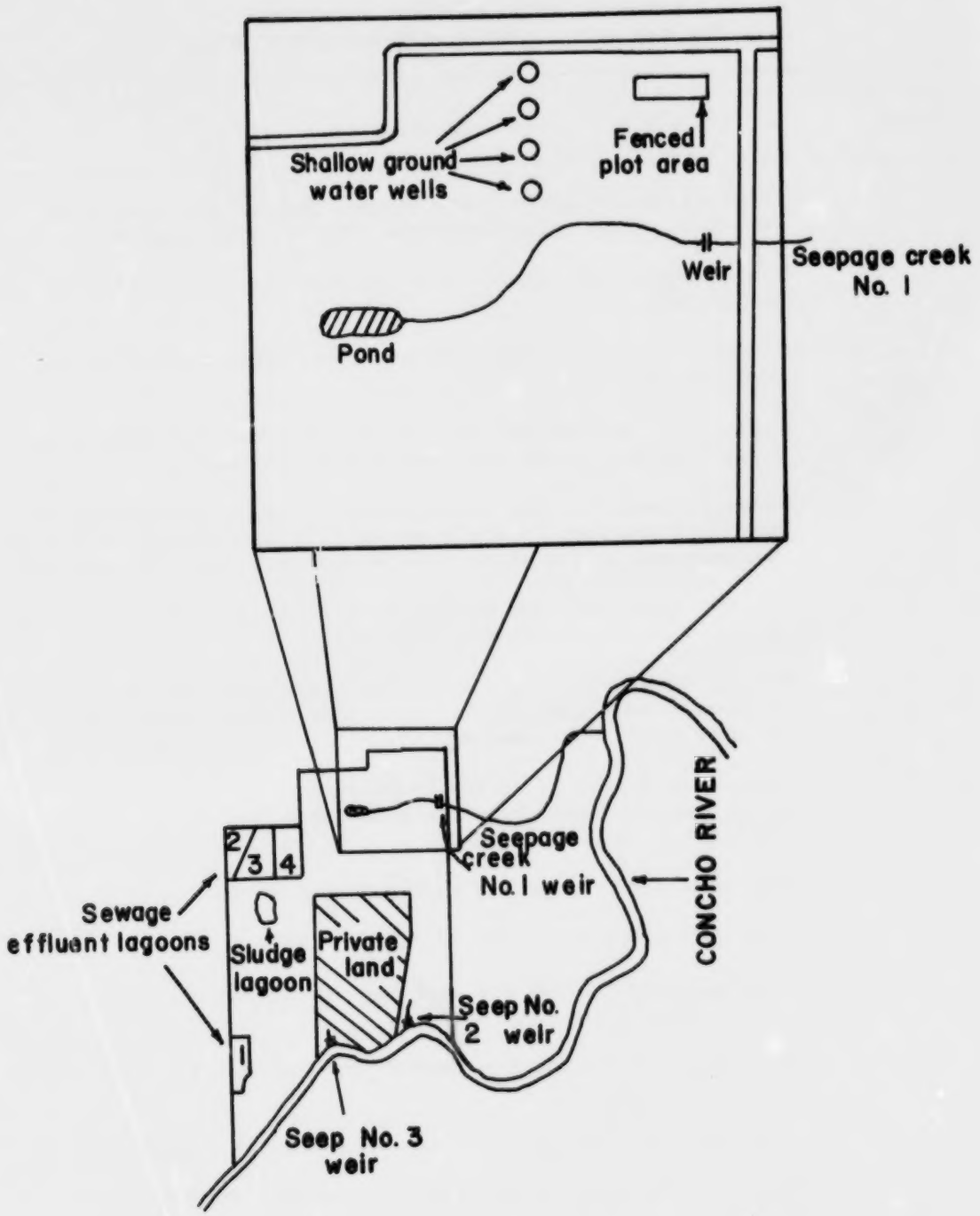


Figure 4. San Angelo sewage farm with blow up of Coastal bermudagrass fenced plot area.

TABLE 5. WATER SAMPLING LOCATIONS
ON THE SAN ANGELO SEWAGE FARM AND CONCHO RIVER

Sampling Number	Location
1	Upstream Concho River: on the west bank of the river 0.64 km south of the bridge over the river on farm road 380
2	Downstream Concho River: 0.84 km down the river from the sewage farm
3	Lagoon #1: on the east side of lagoon directly west of the old clarifier
4	Lagoon #4: on the east side of lagoon where the water overflows from the lagoon into the irrigation mains
5	Seepage creek #1: the large seepage creek on the eastern border of the farm. Sample was taken from the pond created by the weir and on the south side 30 feet upstream from the weir
6	Seepage creek #2: The spring as it flows from the river bank into a pond created by the river weir
7	Seepage creek #3: The spring that flows from the river bank on Mika private land on the north side of the river 2.01 km down river from sampling site #1
8	Shallow well (2.1 m) on the south side of the seepage creek #1 on the bank just above the creek about 180 meters above the weir at sampling site #5
9	Deep well (29.0 m) at the sewage treatment plant
10	Deep well (30.5 m) at the hay barn
11	Deep well (33.6 m) on the west edge of the Carson Farm on the east border of the city farm
12	Deep well (36.6 m) at the cattle pens just north of the sludge lagoon
13	Deep well (27.5 m) at the southeast corner of lagoon #4
14	Deep well (21.4 m) at the earth dammed pond approximately 0.8 km
16	Deep well (30.5 m) at the house 137 m west of sampling site # 11

(continued)

TABLE 5. (continued)

Sampling Number	Location
17	Shallow well (1.2 m) on the north side of seepage creek #1 36.6 m above sampling site #5
18	Shallow well (7.6 m) at the top of the Coastal bermudagrass field in the northeast corner of the sewage farm
19	Shallow well (6.3 m) four borders below sampling site #18 and in the same field.
20	Shallow well (7.8 m) five borders below sampling site #19 and in the same field
21	Shallow well (9.3 m) six borders below sampling site #20 and in the same field
22	The incoming sewage effluent at the sewage treatment plant

TABLE 6. LOCATION AND DEPTH OF WATER SAMPLING SITES OUTSIDE SEWAGE FARM

Sampling Number	Location	Distance and direction from sewage farm		well depth
			Air km	m
31	Veribest	NE	6.4	18
32	Veribest	NE	5.3	24
33	Veribest	SE	6.1	46
34	Veribest	SW	1.6	61
35	San Angelo	N	2.1	37
36	San Angelo	N	2.4	37
37	Red Creek	N	3.2	28
38	San Angelo	NW	10.1	34
39	San Angelo	SW	9.7	18
40	San Angelo	SW	9.7	29
41	San Angelo	SW	7.2	20
42	Wall	S	12.6	42
43	Wall	SE	15.3	41
44	Eula	SE	8.8	46
45	San Angelo	S	4.8	64
46	Wall	SE	14.5	41
47	Eula	SE	11.3	43
48	Veribest	E	5.6	43

16 km radius of the sewage farm. The samples were analyzed and used as background information to compare with that of the sewage farm (Table 6).

Chemical Analysis

Beginning November 18, 1975 waters in the sewage farm were sampled regularly over a one year period for chemical analysis. Samples were taken initially on a weekly schedule and later on a biweekly schedule. Collecting, handling, and analysis of water samples conformed to the general procedures outlined by the U. S. Environmental Protection Agency (1972, 1973, 1974). Analytical procedures used for analysis of water samples are presented in Table 7.

Temperature and pH values were determined on site at the sewage farm. Ammonia-N, nitrate-N, nitrite-N, total Kjeldahl-N, total phosphorus, dissolved orthophosphate, and total heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) were determined at the College Station laboratory. Forms of nitrogen and phosphorus were determined within 24 hours of collection. Water samples were analyzed on two different dates for total filterable residue, total nonfilterable residue, biochemical oxygen demand, and chemical oxygen demand.

SOIL ANALYSIS

Three major soil series (Angelo, Mereta, and Rioconcho) were identified in the San Angelo sewage farm. A total of 15 soil cores were taken from each major soil series with a stainless steel auger (available from Arts Machine Shop, American Falls, Idaho); 10 cores in the sewage farm and 5 cores in an adjacent control area. Soils were taken to a depth of 200 cm, except where a gravel or hard caliche layer existed in the soil profile. The control areas have never been irrigated with sewage effluent. Each core was subdivided into 10 subsamples in varying depth increments. A subsample of each soil was stored in a freezer under field moisture conditions and used immediately for chemical analysis of NH_4^+-N, NO_3^--N, and NO_2^--N. The rest of the soil was air-dried and ground to pass a 1-mm sieve (2-mm for texture analysis) using a mortar and pestle (Table 8).

FIELD PLOT EXPERIMENT AND PLANT ANALYSIS

Twenty-seven experimental plots (1.830 x 4.575 m^2) were established in a fenced Coastal bermudagrass plot area in the sewage farm. The area was fenced to exclude animal movement into the plots but not to exclude irrigation with sewage effluent. These plots were used for biological and chemical tests where recycling of organisms and nutrients through animals was to be avoided.

A factorial experiment (3 x 3 x 3) where combinations of three rates of nitrogen (0, 112.2, and 224.4 kg N/ha as NH_4NO_3) and phosphorus (0, 56.1, and 112.2 kg P_2O_5/ha as 0-20-0) and three replications was designed. These plots were completely randomized in the field. Forage was clipped from the

TABLE 7. METHODS USED FOR CHEMICAL ANALYSIS OF WATERS

Measurement	Method	Reference
1. Temperature	Thermometer	EPA 1974
2. pH	Corning model 7 pH meter	EPA 1974
3. NH_4^+-N	Distillation with MgO and collected in H_3BO_3	Bremner 1965b
4. NO_3^--N	Brucine sulfate	EPA 1974
5. NO_2^--N	Diazotation of sulfanilamide	EPA 1974
6. Total Kjeldahl nitrogen	Hot, concentrated H_2SO_4 digestion and distillation with NaOH	EPA 1974
7. Total Phosphorus	HNO_3-$HClO_4$ digestion and antimony-phospho-molybdate complexation	APHA 1976 Murphy & Riley 1962
8. Dissolved orthophosphate	Antimony-phospho-molybdate complexation	EPA 1974 Murphy & Riley 1962
9. Heavy metals	HNO_3 digestion and HCl dissolution	EPA 1974
10. COD	Digestion with potassium dichromate and back titration with ferrous ammonium sulfate	APHA 1976
11. BOD	Incubation for 5 days at 20°C followed by O_2 analysis with Yellow Springs model 57 dissolved oxygen meter	APHA 1976
12. Total filterable residue	Filtering through 0.45 μ millipore filter paper and dried at 180°C	EPA 1974
13. Total nonfilterable residue	Filtering through 0.45 μ millipore filter paper and dried at 105°C	EPA 1974

TABLE 8. EQUIPMENT AND METHODS USED IN SOIL ANALYSIS

Measurement	Method	Reference
1. Texture	Bouyoucous hydrometer	Day 1965
2. Bulk density	Core method	Blake 1965
3. pH	Metrohm/Brinkmann model pH-103 pH meter	Peech 1965
4. Carbonate	Acid-neutralization	Allison and Moodie 1965
5. Organic matter	Walkley-Black method	Jackson 1958
6. Cation exchange capacity	pH 7.0 1N NH_4OAc extraction and Kjeldahl distillation	Keeney and Bremner 1969
7. Soluble salts	Industrial Instruments Inc. Model RC 16B2 conductivity bridge	Bower and Wilcox 1965
8. Total phosphorus	$HClO_4$ digestion and vanadate molybdate color method	Kao and Blancher 1975, Tandon, et al, 1968
9. Water soluble Phosphorus	1:10 soil-water extraction and ascorbic acid method	Olsen and Dean 1965, Murphy and Riley 1962
10. Total nitrogen	Kjeldahl digestion and distillation	Bremner 1965 a.
11. NO_3^--N	1:10 soil-2N KCl extraction and brucine sulfate color method	Bremner 1965 b. EPA 1974
12. NH_4^+-N	1:10 soil 2N KCl extraction and kjeldahl distillation with MgO	Bremner 1965 b.
13. NO_2^--N	1:10 soil-2N KCl extraction and diazotation of sulfanilamide	Bremner 1965 b. EPA 1974
14. acid-extractable heavy metals	1:2 soil-1N HCl extraction and determination by using a Perkin-Elmer Model 403 atomic adsorption spectrophotometer	Lagerwerff 1971
15. Total heavy metals	HNO_3-$HClO_4$ digestion and determination using a Perkin-Elmer model 403 atomic absorption spectrophotometer	Kao and Blanchar 1973

experimental plots twice during the active growing season. Yield of forage grass was calculated from the plot weights. Yield of major grass crops in other areas of the sewage farm was also determined. Once dry matter yield was measured, the plant tissue was used for chemical analysis. Plant tissue was dried at 75°C for 24 hours and ground with a Wiley Mill to pass through a 40 mesh sieve prior to analysis.

Total phosphorus was determined by the procedure reported by Kao and Blanchar (1973) and Tandon et al. (1968). The semimicro Kjeldahl method was used to determine the total nitrogen concentration (Bremner, 1965a). Heavy metals were determined by digesting a suitable amount of plant tissue in hot, concentrated HNO_3 and $HClO_4$ in a micro-Kjeldahl flask (Perkin-Elmer Corp. 1971) and analyzed with a Perkin-Elmer Model 403 Atomic Adsorption Spectrophotometer.

STATISTICAL ANALYSIS

All field and laboratory data were processed and analyzed by the Statistical Analysis System (Barr et al., 1976) on an IBM 370 computer at Texas A & M University.

SECTION 6

RESULTS AND DISCUSSION

HYDROLOGY AND METEROLOGY

Meteorology

The climate of San Angelo, Texas is semiarid to subhumid. The average annual precipitation is 52.78 cm with about 85 percent of the precipitation falling between mid-March and mid-November. On the average, rain or snow falls during all or parts of 42 days a year. Freezing temperatures occur at intervals between mid-November and mid-March (Willis 1954). The data presented in Figure 5 show average monthly precipitation from 1936 to 1975 and monthly precipitation in 1976 at the sewage farm. The precipitation was 64.29 cm in 1976, about 22 percent higher than the average of the last 40 years.

Temperatures of air, soil at 10 cm depth, and soil at 40 cm depth are shown in Figure 6. Soil temperatures fluctuated less than the air temperature. There was little difference between the soil temperature at 10 cm and at 40 cm. Soil temperatures at 40 cm ranged from a high of 30°C to a low of +5°C. Air temperatures fluctuated between a high of 31°C to a low of -1°C. Maximum soil temperatures at 10 and 40 cm depths are about 50 days behind the maximum air temperature. Both the soil temperature at 10 cm depth and soil temperature at 40 cm depth show the same pattern.

Hydrology

Water flow rates of the Concho River measured on 32 separate days in 1976 upstream and downstream from the sewage farm are shown in Table 9. The mean water flow rates upstream and downstream from the sewage farm were 1.0007 and 1.1436 m^3/sec. This indicates a net contribution of 0.1429 m^3/sec from the sewage farm to the Concho River. It was calculated that, on the average, the San Angelo sewage farm contributed about 12.5 percent of the total water flow of the Concho River downstream from the sewage farm in 1976 (Table 10). Data presented in Figure 7 show the water flow rates of the three seepage creeks monitored on the sewage farm. Seepage creek no. 1 had a daily mean flow rate of 1,009.5 liters per minute. Flow rates ranged from 53.0 to 3,225.1 liters per minute with a daily mean standard deviation of 465.9 liters per minute. Seepage creek no. 2 had a daily mean flow rate of 166.6 liters per minute and ranged from 2.5 to 550.0 liters per minute with a daily mean standard deviation of 33.5 liters per minute. The mean flow rate of seepage creek no. 3 was 97.6 liters per minute with a range of 17.9 to 525.0 liters per minute and a daily mean

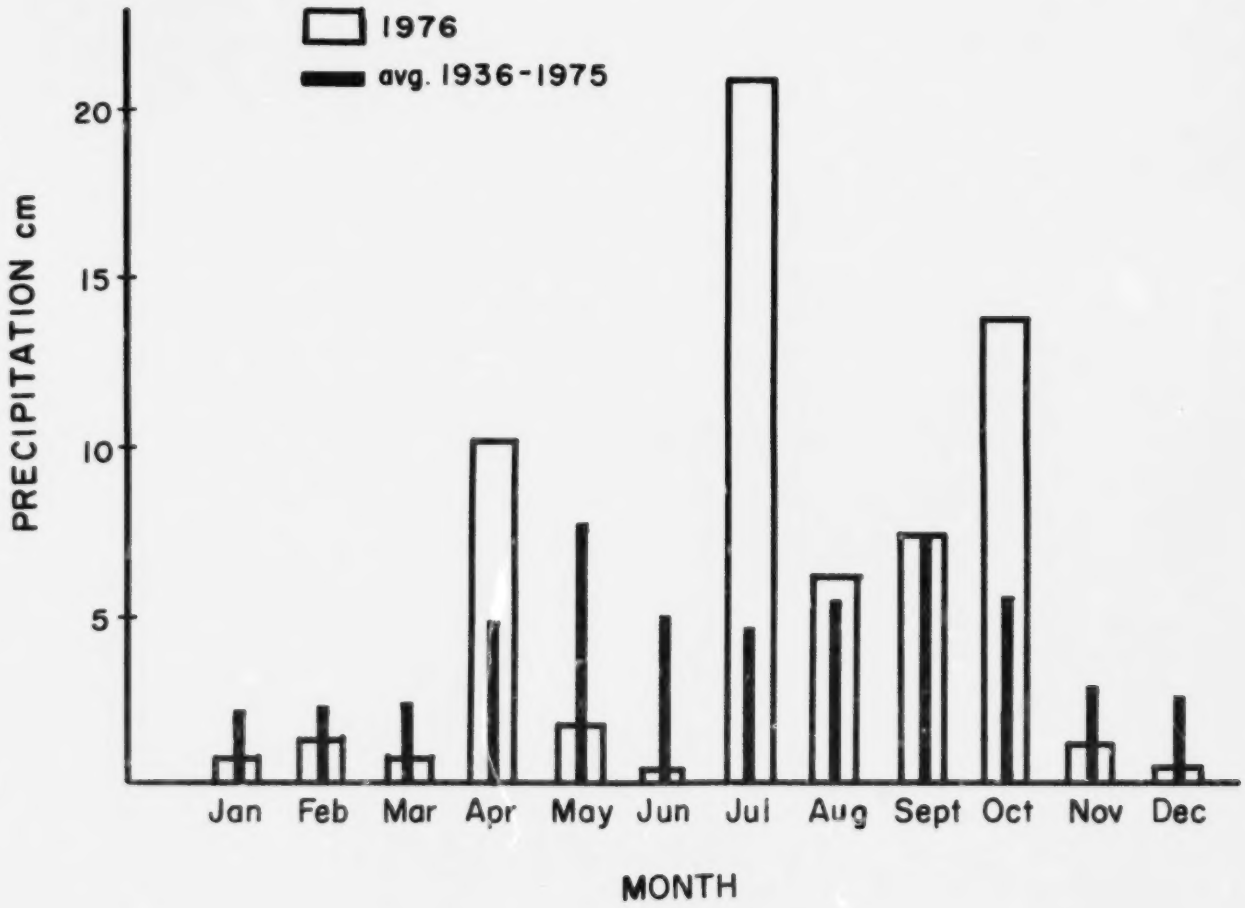


Figure 5. Average monthly precipitation for the years 1936 - 1975 and monthly precipitation in 1976 at the San Angelo sewage farm, Tom Green County, Texas.

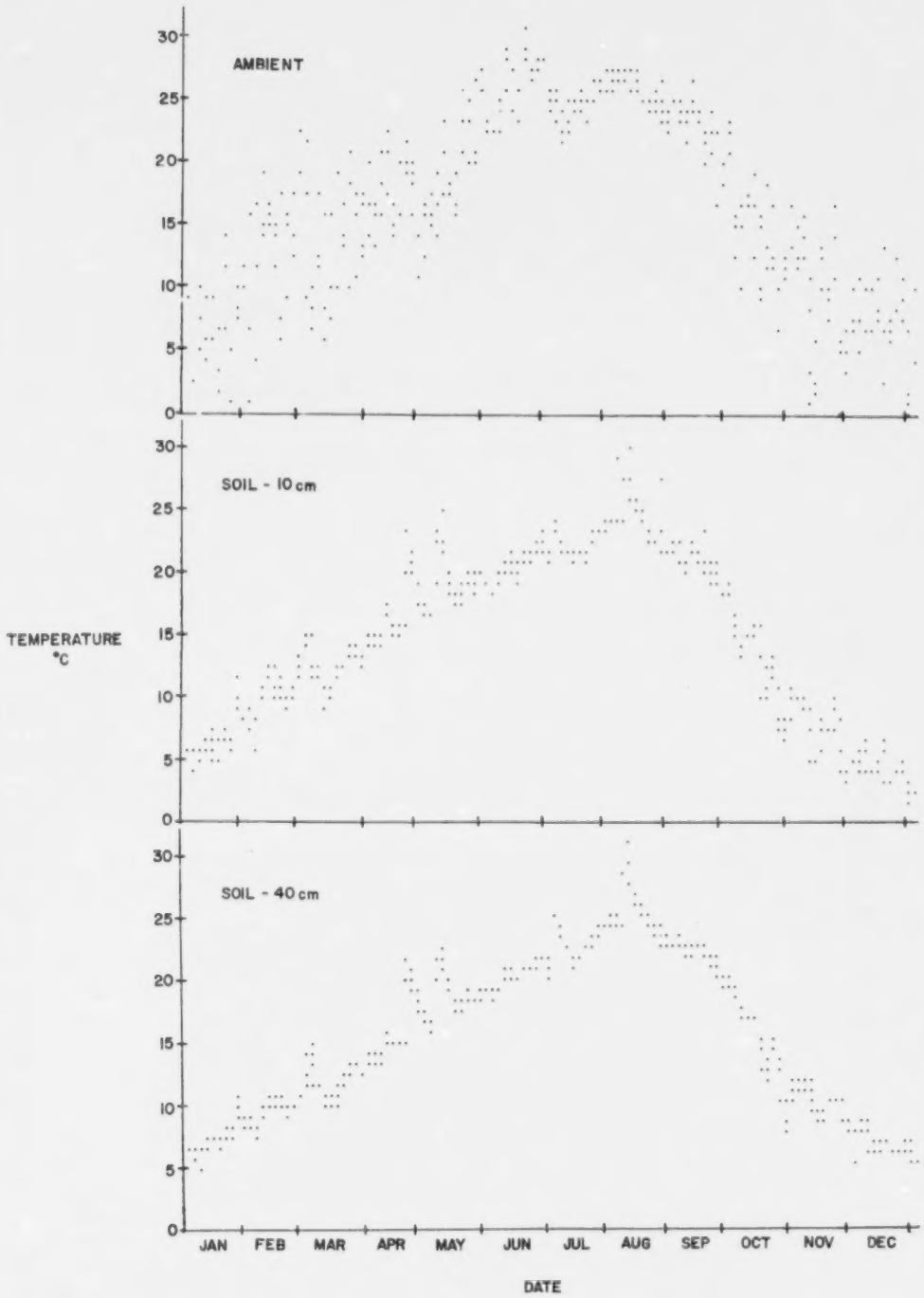


Figure 6. Daily mean temperatures of air, soil at 10 cm and 40 cm depths at San Angelo sewage farm in 1976.

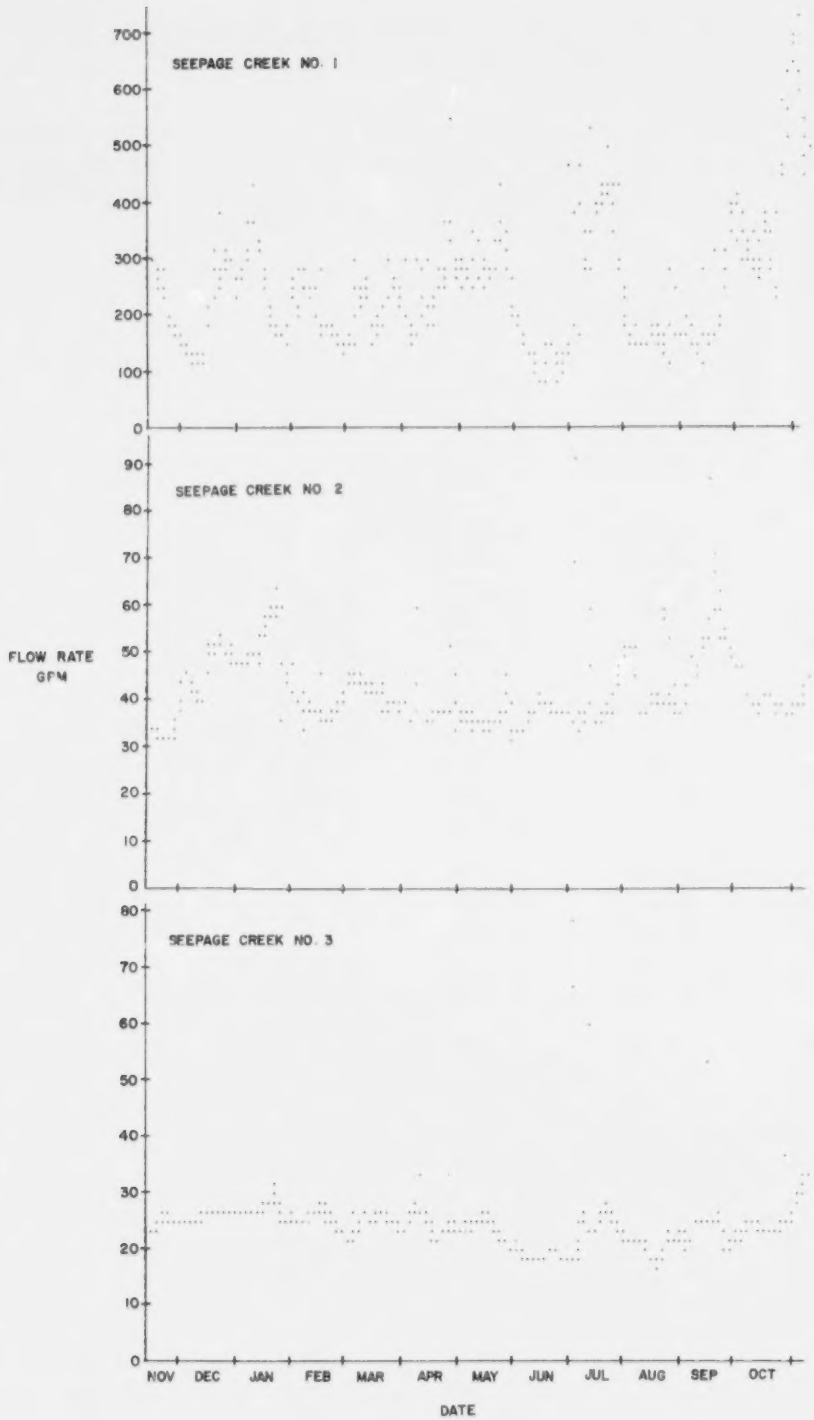


Figure 7. Water flow rates of three seepage creeks monitored on the San Angelo sewage farm.

TABLE 9. WATER FLOW RATES OF CONCHO RIVER UPSTREAM AND DOWNSTREAM FROM THE SEWAGE FARM IN 1976

Date	Water flow rate			$\frac{\text{Difference}}{\text{Downstream}} \times 100$
	Downstream	Upstream	Difference	
	---------- m^3/sec ----------			%
760129	1.2899	1.2299	0.0600	4.65
760205	0.7399	0.6700	0.0699	9.46
760212	0.8899	0.7199	0.1700	19.11
760219	1.0599	0.9499	0.1100	10.38
760226	0.5900	0.5300	0.0600	10.17
760304	0.7799	0.6300	0.1499	19.23
760311	0.8999	0.7599	0.1400	15.56
760316	0.8500	0.6999	0.1501	17.65
760325	0.8059	0.7629	0.0430	5.33
760401	0.6920	0.5870	0.1050	15.17
760408	0.9570	0.8980	0.0590	6.16
760415	1.1419	0.9699	0.1720	15.06
760422	0.9590	0.8770	0.0820	8.55
760430	2.3429	2.1548	0.1881	8.02
760511	1.2659	0.9759	0.2900	22.91
760527	0.9789	0.8170	0.1619	16.54
760610	0.4910	0.3380	0.1530	31.16
760623	0.3750	0.3510	0.0240	6.41
760708	0.7500	0.6159	0.1341	17.87
760719	2.1858	1.8399	0.3459	15.83
760728	1.4569	1.1609	0.2960	20.31
760813	0.7759	0.6669	0.1090	14.05
760830	1.7859	1.5539	0.2320	12.99
760908	1.5500	1.4901	0.0599	3.87
760922	1.1930	0.9961	0.1969	16.51
761001	0.8580	0.7520	0.1060	12.35
761014	1.1790	1.0361	0.1429	12.13
761022	1.2739	1.2159	0.0580	4.55
761025	1.4619	1.1369	0.3250	22.23
761103	1.6669	1.5079	0.1590	9.54
761124	1.3289	1.1739	0.1550	11.66
	2.0229	1.9548	0.0681	3.36
mean	1.1436	1.0007	0.1429	12.50

TABLE 10. AVERAGE WATER FLOW RATES OF THE CONCHO RIVER UPSTREAM AND DOWNSTREAM FROM THE SEWAGE FARM AND OF THREE SEEPAGE CREEKS AT THE SEWAGE FARM FOR 1976

Location	Flow rate		
	GPM	MGD	m^3/sec
Concho River upstream from sewage farm	15861.0	22.840	1.0007
Concho River downstream from sewage farm	18127.0	26.103	1.1436
Sewage farm output*	2266.0	3.263	0.1429
Seepage creek no. 1	266.7	0.384	0.0168
Seepage creek no. 2	44.0	0.063	0.0028
Seepage creek no. 3	25.7	0.037	0.0016
Sum of three seepage creeks	336.4	0.484	0.0212
Average percentage contribution of three seepage creeks to sewage farm output.			14.85%
Average percentage contribution of sewage farm output to downstream Concho River.			12.50%

*Difference from upstream to downstream

standard deviation of 24.1 liters per minute. It was calculated that these three seepage creeks contributed about 14.85 percent of the water flowing into the Concho River from the sewage farm (Table 10). Approximately 100 active seeps have been observed discharging water to the Concho River (Texas Water Quality Board 1973).

The wastewater that is being constantly applied to the sewage farm is apparently percolating to the shallow bedrock layer and moving laterally to the Concho River. Discharge measurements made on October 24, 1973 in the Concho River above and below the sewage farm by Texas Water Quality Board indicated that on that date 0.2747 m^3/sec entered the river. This volume made up approximately 43 percent of the flow in the river downstream from the sewage farm. The highest percentage contribution of water from the sewage farm to the Concho River measured in 1976 was 31.2 percent on June 10, whereas the lowest value was 3.4 on December 10 (Table 9).

The Concho River originates in central Tom Green County at the confluence of the north and south forks and flows through Tom Green and Concho Counties in an eastward direction to its mouth with the Colorado River, a distance of approximately 85 km. The city of San Angelo's sewage treatment plant has a permitted discharge volume of 0.2234 m^3/sec (Texas Water Quality Board 1973). The discharge of treated sewage effluent from the city of San Angelo's sewage treatment plant is significantly increasing the flow of the Concho River. At the present time a new activated sludge wastewater treatment plant that will discharge an average of 0.3198 m^3/sec of treated domestic sewage to the farm is being constructed.

WATER ANALYSIS

One of the purposes of this portion of the study was to evaluate the environmental impact of the city of San Angelo's sewage treatment plant discharge on the water quality of the receiving Concho River. At the present time no absolute water quality criteria values are available. Water quality criteria, published by U. S. Environmental Protection Agency in 1976, were based on the concentration-effect relationship of a particular water quality constituent upon a particular aquatic species within the limits of experimental investigation. However, those water quality criteria published by the U. S. Environmental Protection Agency (EPA 1976) will be used to evaluate the waters in the sewage farm and in Tom Green County. As stated in that publication, those water quality criteria levels should provide for the protection and propagation of fish and other aquatic life and for recreation in and on water in accord with the 1983 goals of Public Law 92-500. Water quality criteria published by the National Technical Advisory Committee (NTAC) to the secretary of the Interior (NTAC, 1968) will also be used. Furthermore, water quality criteria from states having the most stringent standards will be also used as a reference (Lykins and Smith, 1976).

Water sampling locations at the sewage farm and in Tom Green County are shown in Figures 8 and 9.

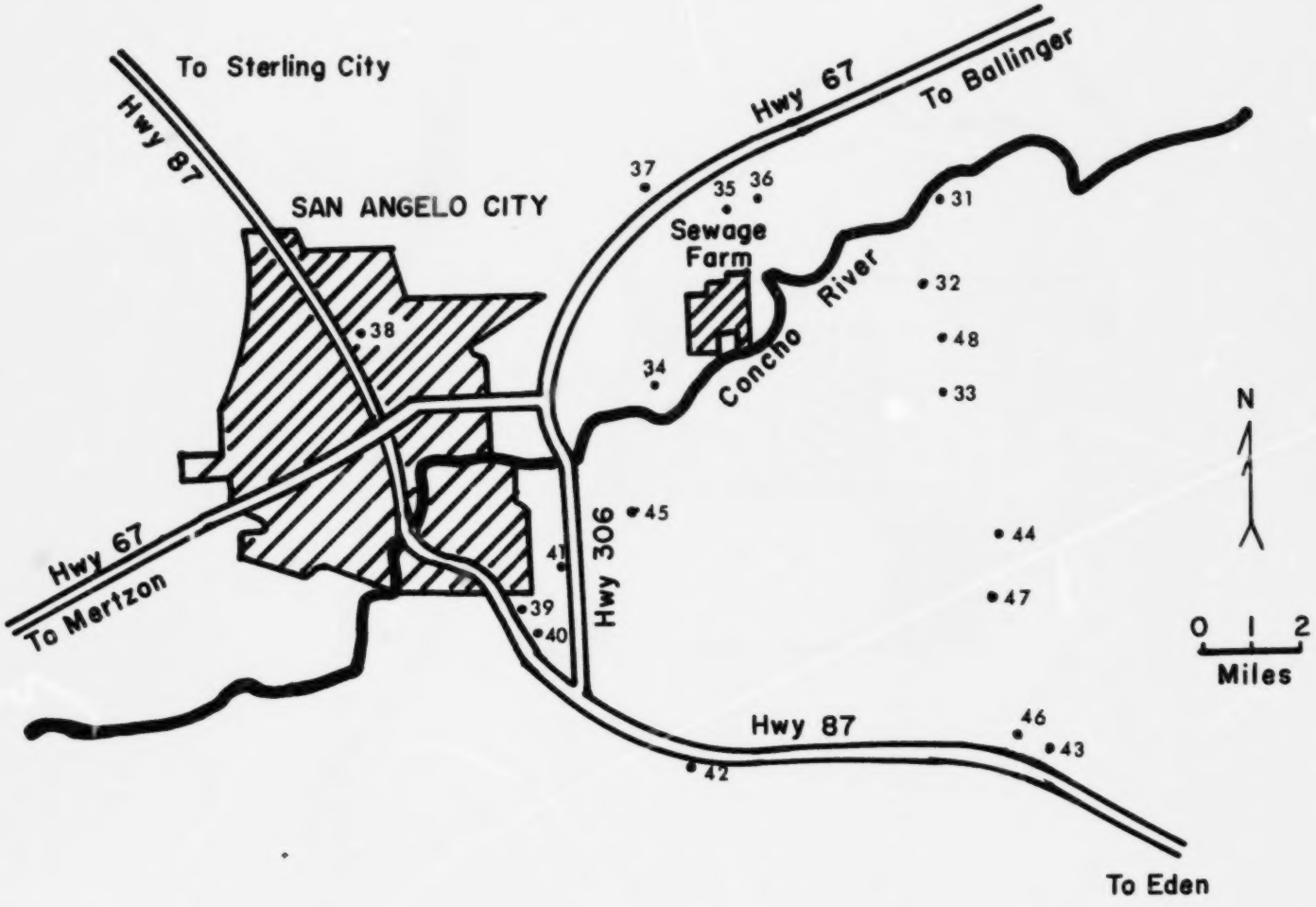


Figure 8. Well water sampling locations in Tom Green County, Texas.

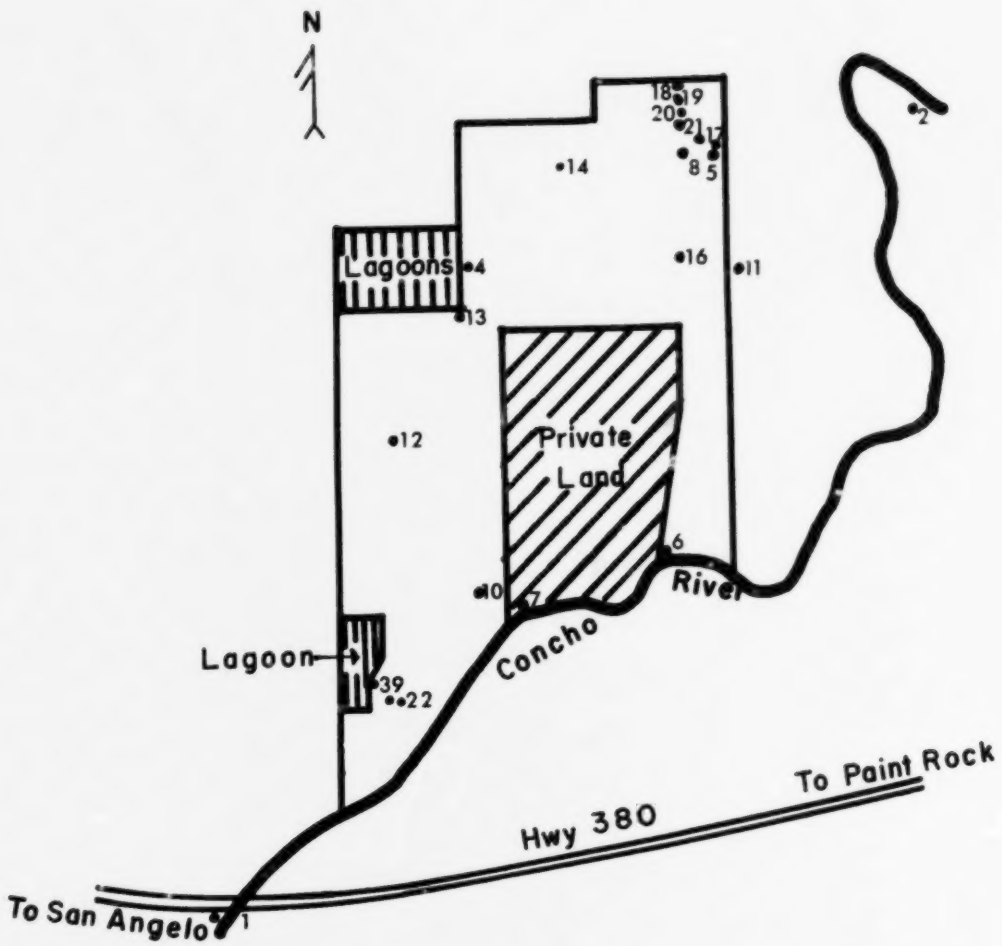


Figure 9. Surface and well water sampling locations at the San Angelo sewage farm and Concho River.

Data presented in Tables 11 through 18 summarize water analyses of the incoming sewage effluent, effluent lagoons 1 and 4, seepage creeks 1, 2 and 3, and the concentration of nutrients in the Concho River above and below the sewage farm. The chemical composition of water from shallow and domestic wells on the sewage farm is summarized in Table 19. Eighteen domestic wells were monitored on an irregular basis outside the perimeter of the sewage farm during 1976. These data are presented in Table 20. Finally, biological oxygen demand (BOD) and chemical oxygen demand (COD) are presented for all sampling sites in Table 21.

Temperature

Solution temperatures varied with the time of year of sampling. Sample temperatures were as low as 3.8°C on January 3, 1976 at lagoon number 1 and as high as 32.6°C on July 7, 1976 at lagoon no. 4. Temperature fluctuations of water from seepage creeks 2 and 3 were very small, ranging from 18.9 to 21.5°C for the duration of the study (Tables 15 and 16).

pH

The discharge of water from the sewage farm into the Concho River had no effect on the pH values of the Concho River below the sewage farm (Tables 17 and 18). A small increase in pH value and ammonia-nitrogen concentration was observed in the incoming sewage effluent at the sewage treatment plant and lagoon no. 4. Ammonification of organic nitrogen and dissolution of ammonia in wastewater increase both the pH and ammonia-nitrogen in wastewater. All three seepage creeks, shallow ground wells, domestic deep wells at the sewage farm, and Tom Green County deep wells had pH values of 7.2 ± 0.2.

Nitrogen

Ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), and organic nitrogen are the most important forms of nitrogen in the nitrogen cycle. The NH_4^+ ion is either released from proteinaceous organic matter and urea (Ammonification), or is synthesized in industrial processes involving atmospheric nitrogen fixation. The NO_3^- ion is formed by the biochemical oxidation of NH_4^+ to NO_3^- (nitrification); NO_2^- is an intermediate product of the nitrification process. The NO_2^- ion is formed from the NH_4^+ or the NO_3^- ions by certain biochemical processes (nitrification). In an aerobic condition NO_2^- is rapidly oxidized to NO_3^-. Plants can take up both NH_4^+ and NO_3^- ions and convert them to protein. When nitrogen in sewage effluent which is mostly in the NH_4^+ form is applied to an aerobic soil, the NH_4^+ will be converted to NO_3^-. Some of the nitrogen may be used by plants, some may be lost by denitrification as molecular nitrogen and nitrogen oxides or volatilization as ammonia (NH_3), and some may be leached down to the ground water as NO_3^-.

A limit of 10 µg/ml of nitrogen as NO_3^- plus NO_2^- ion is recommended as a domestic water supply standard (EPA 1976). Waters containing NO_3^- plus

TABLE 11. CHEMICAL ANALYSIS OF RAW SEWAGE FROM FEBRUARY 18, 1976 TO NOVEMBER 11, 1976, COLLECTED FROM THE SEWAGE TREATMENT PLANT

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
760218[b]	850	19.0	7.4	18.2	0.1	ND[c]	24.6	5.25	12.00	110	120	ND	8	375	ND
760225	900	18.4	7.0	18.0	0.1	ND	27.0	5.48	11.25	200	130	ND	7	320	80
760303	920	20.8	7.1	17.1	ND	7	27.4	5.25	10.25	170	120	15	ND	225	230
760310	935	14.0	7.6	29.2	ND	9	36.4	13.30	22.25	48	64	17	ND	80	100
760315	1020	19.3	7.3	16.2	ND	ND	23.8	5.63	11.25	130	100	15	ND	140	ND
760324	845	20.4	7.2	18.1	ND	6	24.9	5.50	14.00	115	92	15	ND	150	170
760331	930	19.3	7.2	17.7	ND	8	23.7	5.75	11.63	325	100	10	5	205	100
760407	945	20.5	7.3	16.0	ND	7	23.0	5.38	12.38	155	83	20	5	540	ND
760414	1000	22.7	7.1	13.2	0.1	11	20.0	4.25	8.00	178	87	15	ND	440	50
760421	820	21.8	7.4	17.1	ND	9	23.9	7.38	14.13	109	92	20	8	420	ND
760510	825	23.0	7.1	18.8	ND	19	26.6	5.58	10.75	191	80	15	ND	660	ND
760526	915	25.0	7.2	15.7	1.5	21	20.7	5.00	9.63	117	108	25	8	400	ND
760609	855	26.0	7.3	15.5	0.2	ND	22.5	4.75	7.00	190	87	30	ND	400	ND
760624	948	27.8	7.0	13.8	0.1	19	19.2	4.13	8.88	79	78	12	5	140	ND
760707	940	26.5	7.3	13.7	0.2	7	17.0	4.37	7.00	94	76	10	ND	210	ND
760722	1015	26.8	7.1	16.3	0.3	10	19.2	4.37	8.00	90	93	33	ND	200	ND
760805	945	28.2	7.0	13.6	0.1	11	22.2	4.25	6.90	140	73	19	4	ND	ND
760831	915	28.0	7.2	12.9	0.5	8	16.9	3.75	5.88	142	78	ND	14	380	50
760916	900	27.9	7.3	14.5	0.3	30	16.6	3.75	5.25	96	87	ND	ND	ND	50
760928	1012	26.0	7.4	15.1	0.1	53	17.6	3.13	7.50	190	81	ND	ND	425	50
761019	1012	23.9	7.1	15.8	0.4	32	20.2	3.55	7.68	87	76	12	5	200	ND
761103	905	19.8	7.1	12.0	0.2	11	17.2	3.28	6.75	70	82	14	5	200	ND
761111	1005	20.6	7.4	15.5	0.2	11	19.6	3.75	7.75	120	70	17	5	145	ND
Mean		22.9	7.2	16.3	0.2	15	22.2	5.08	9.83	137	89	14	< 4	272	< 50
Maximum		28.2	7.6	29.2	1.5	53	36.4	13.30	22.25	325	130	33	14	660	230
Minimum		14.0	7.0	12.0	< 0.1	< 5	16.6	3.13	5.25	48	64	< 10	< 4	< 5	< 50
Standard Deviation		3.9	0.2	3.4	0.3	12	4.6	2.05	3.71	59	17	9	4	169	62
Annual input[a], 10^3 Kg/year				112.6	1.4	0.090	153.3	35.1	67.9	0.946	0.615	0.097	—	0.188	—

[a] Assume 5 mgd (6.908×10^9 liters/year) incoming sewage effluent.
[b] Year, month, day
[c] Not detectable

TABLE 12. CHEMICAL ANALYSIS OF WATER SAMPLES FROM NOVEMBER 18, 1975 TO NOVEMBER 11, 1976 TAKEN FROM LAGOON NO. 1 LOCATED ON THE SAN ANGELO SEWAGE FARM

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
751118[a]	415	18.0	7.2	29.7	ND[b]	5	34.9	11.25	14.63	350	110	ND	ND	200	150
751125	845	12.0	7.2	27.8	0.4	ND	39.9	11.50	40.63	330	140	40	ND	150	100
751202	1000	10.0	7.3	28.1	0.5	6	40.1	11.98	19.00	240	200	ND	ND	150	150
751209	925	9.5	7.4	30.1	0.4	5	40.7	10.20	30.00	450	110	20	ND	300	200
751216	915	11.0	7.4	28.6	0.2	9	39.9	13.00	21.10	220	100	20	ND	150	150
751222	900	8.9	7.3	28.8	0.2	ND	39.3	13.30	13.80	170	80	ND	ND	100	100
760101	1014	8.2	7.2	30.8	0.1	9	37.2	14.00	25.00	80	60	ND	ND	80	150
760103	1050	3.8	7.3	30.0	0.2	23	29.1	15.30	58.80	80	50	ND	ND	70	ND
760112	1245	9.1	7.4	32.5	0.1	ND	40.1	14.50	18.25	100	50	20	ND	70	ND
760121	1010	8.8	7.5	33.8	0.2	15	35.4	15.50	29.80	150	50	20	ND	80	ND
760128	1100	8.2	7.5	32.6	0.3	5	39.9	15.75	29.30	140	60	ND	ND	100	ND
760204	900	11.0	7.4	33.4	0.2	ND	38.0	16.25	24.88	120	20	30	ND	80	ND
760211	845	13.0	7.6	33.2	ND	ND	38.7	15.75	22.75	180	70	20	ND	100	ND
760218	840	13.2	7.4	33.4	ND	ND	41.1	14.75	28.75	100	70	20	12	140	50
760225	930	11.2	7.2	34.0	ND	8	46.5	16.48	26.25	150	60	20	8	140	ND
760303	855	18.0	7.0	30.7	0.1	9	45.3	16.00	27.50	230	110	20	5	210	230
760310	905	14.2	7.1	32.3	ND	8	42.8	15.50	32.50	246	130	13	ND	190	230
760315	950	13.0	7.2	33.0	0.2	ND	45.9	16.00	27.50	140	57	20	ND	80	70
760324	830	15.9	7.2	32.3	0.1	16	42.8	15.00	28.13	165	92	45	ND	120	170
760331	945	15.8	7.2	35.1	0.1	8	47.8	13.75	29.38	105	70	20	6	95	70
760407	1030	18.0	7.3	40.3	0.1	19	44.0	15.00	27.50	111	65	25	5	102	ND
760414	945	22.2	7.1	37.3	0.1	20	48.4	13.75	26.25	111	58	15	5	105	ND
760421	845	20.0	7.3	36.5	0.1	11	55.3	13.25	21.25	245	95	20	10	230	120
760510	800	19.0	7.3	33.5	0.2	9	45.6	9.00	18.75	130	49	20	6	88	70
760526	845	24.4	7.6	23.7	0.7	13	45.2	8.00	21.87	111	51	ND	7	90	ND
760609	910	24.3	7.2	24.0	0.3	13	47.2	6.63	21.25	135	54	20	6	88	50
760624	1015	25.8	7.5	21.1	0.3	5	57.5	1.25	29.75	130	57	15	ND	80	50
760707	905	26.6	7.5	20.1	0.7	29	44.2	2.00	23.00	70	56	16	ND	70	ND
760722	940	26.2	7.1	18.5	0.3	29	33.8	4.75	24.00	1540	8060	2200	ND	65	ND
760805	920	27.8	7.1	19.3	0.3	23	36.4	6.63	22.00	80	50	42	4	66	50
760831	850	26.0	7.1	18.1	0.4	10	36.4	7.75	21.00	93	48	10	ND	150	50
760916	845	24.7	7.2	19.0	0.5	34	24.0	7.50	18.25	106	64	10	ND	240	100
760928	950	22.1	7.4	17.5	0.2	45	35.2	6.45	19.50	118	50	10	5	120	175
761019	948	15.8	6.3	18.7	0.2	8	37.9	7.75	19.00	62	37	12	5	90	ND
761103	845	13.0	7.5	18.6	0.3	16	31.7	6.50	18.40	62	60	20	ND	95	ND
761111	915	19.2	7.0	20.3	0.2	16	36.1	6.75	20.00	150	118	20	5	180	ND
Mean		16.3	7.3	23.2	0.2	12	40.7	11.35	24.94	194	296	77	< 4	124	69
Maximum		27.8	7.6	40.3	0.7	45	57.5	16.48	58.80	1540	8060	2200	12	300	230
Minimum		3.8	7.0	17.5	< 0.1	< 5	24.0	1.25	13.80	62	20	< 10	< 4	65	< 50
Standard deviation		6.6	0.2	6.6	0.2	11	6.6	4.36	8.02	246	1331	364	3	57	75

[a] Year, month, day
[b] Not detectable

TABLE 13. CHEMICAL ANALYSIS OF WATER SAMPLES FROM NOVEMBER 18, 1975 TO NOVEMBER 11, 1976 TAKEN FROM LAGOON NO. 4 LOCATED ON THE SAN ANGELO SEWAGE FARM

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
751118[a]	405	18.0	8.0	19.4	ND[b]	5	29.9	3.34	9.63	110	120	ND	ND	100	ND
751125	130	10.5	8.2	20.8	0.3	5	29.0	8.75	50.00	90	80	ND	ND	70	ND
751202	230	17.0	7.8	23.4	0.5	16	31.6	8.13	20.00	110	80	ND	ND	90	ND
751209	150	14.5	7.3	25.7	0.7	5	28.8	8.60	22.50	280	80	ND	ND	100	ND
751218	155	14.4	8.2	26.4	0.2	13	31.7	10.00	18.40	140	60	20	ND	90	ND
751222	1225	10.8	7.9	30.3	0.7	6	33.6	11.00	12.50	80	60	ND	ND	70	ND
760101	155	8.8	7.2	26.0	0.2	6	31.5	10.50	21.30	70	50	ND	ND	70	100
760108	315	6.5	8.0	26.2	0.3	8	32.0	11.30	21.30	60	ND	ND	ND	70	ND
760112	415	9.2	7.7	26.9	0.1	9	32.2	12.30	12.50	70	40	ND	ND	40	ND
760121	310	11.0	7.7	27.7	0.1	9	23.5	12.00	25.00	120	30	30	ND	60	ND
760128	415	11.2	7.6	27.6	0.1	ND	32.3	9.50	25.00	110	60	ND	ND	70	ND
760204	1245	15.0	7.8	26.6	0.2	6	29.1	12.75	20.38	40	ND	ND	ND	40	ND
760211	120	15.0	7.9	27.7	ND	6	22.6	12.75	20.13	140	70	20	8	90	ND
760218	135	19.5	7.6	26.5	0.1	13	33.5	12.25	23.13	70	70	20	10	98	ND
760225	230	14.5	7.5	25.7	ND	17	33.8	12.50	17.50	20	50	ND	ND	100	ND
760303	120	21.0	7.7	24.6	0.1	6	33.7	12.00	18.60	180	50	ND	ND	70	ND
760310	215	17.0	7.9	24.6	ND	18	32.9	12.00	22.50	258	54	10	ND	70	70
760315	340	21.7	7.7	24.9	0.1	6	35.4	11.00	21.30	720	54	15	ND	63	ND
760324	1000	17.0	7.6	22.5	ND	56	34.1	11.00	18.13	77	51	10	ND	63	70
760331	1045	17.0	7.5	24.0	ND	10	33.6	11.50	20.63	92	54	15	17	95	ND
760407	230	22.0	7.8	21.7	0.1	17	28.8	9.38	19.75	410	46	20	5	65	ND
760414	415	26.0	7.9	19.7	0.1	19	31.2	4.50	12.50	238	42	15	ND	60	ND
760421	1115	22.8	8.0	19.1	0.2	11	30.9	2.00	15.00	290	46	20	6	59	ND
760510	925	20.3	7.6	18.6	0.3	23	28.8	1.50	13.75	150	40	20	6	59	ND
760526	1035	23.0	7.1	17.5	2.5	125	35.4	5.50	23.12	74	40	ND	7	43	ND
760609	1000	24.8	7.6	16.3	0.4	20	32.7	4.88	13.75	175	42	30	8	40	50
760624	1130	27.9	—	14.4	0.3	ND	39.3	4.00	21.50	160	37	11	ND	35	50
760707	320	32.6	7.6	11.8	0.3	50	25.2	0.13	16.00	440	38	10	ND	34	ND
760722	1135	27.8	7.2	13.4	0.6	26	24.1	2.15	17.50	72	76	42	ND	63	ND
760805	140	30.0	7.4	12.8	0.3	34	24.6	6.00	14.50	320	160	42	4	21	ND
760831	1035	28.0	8.2	11.7	0.4	5	20.4	5.00	13.00	120	25	ND	ND	47	ND
760916	1100	26.3	7.5	13.4	0.2	19	26.1	0.17	11.75	85	31	ND	ND	53	ND
760928	1118	22.2	7.8	15.0	0.3	14	23.7	3.75	15.10	92	36	10	ND	57	50
761019	207	17.3	7.4	14.5	0.3	18	26.2	1.88	12.50	207	31	12	5	55	ND
761103	1030	15.0	8.0	15.2	0.4	15	22.0	3.45	12.00	53	58	17	ND	60	ND
761111	1135	16.0	7.8	17.9	0.3	14	23.0	5.38	12.00	160	46	17	5	45	ND
Mean		18.7	7.7	21.1	0.3	18	29.8	7.58	18.45	163	53	11	< 4	64	< 50
Maximum		32.6	8.2	30.3	2.5	125	39.3	12.75	50.00	720	160	42	17	100	100
Minimum		6.5	7.1	11.7	< 0.1	< 5	20.4	0.13	9.63	20	< 10	< 10	< 4	21	< 50
Standard deviation		6.5	0.3	5.5	0.4	22	4.4	4.16	6.92	138	29	12	4	21	26

[a] Year, month, day
[b] Not detectable

TABLE 14. CHEMICAL ANALYSIS OF WATER SAMPLES FROM NOVEMBER 18, 1975 TO NOVEMBER 11, 1976 TAKEN FROM SEEPAGE CREEK NO. 1 ON THE SAN ANGELO SEWAGE FARM

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	----------	µg/ml	----------	----------	----------	ng/ml	----------	----------	----------
751118[a]	210	21.0	7.5	ND[b]	6.9	55	1.1	0.15	0.19	30	30	ND	ND	ND	ND
751125	1125	12.5	7.4	ND	10.3	44	1.2	0.11	0.21	20	ND	110	ND	ND	ND
751202	1235	16.0	7.6	ND	9.4	18	1.9	0.15	0.37	90	30	20	ND	ND	ND
751209	1200	14.0	7.6	ND	12.8	41	0.9	0.19	0.20	70	20	ND	ND	ND	ND
751216	1130	13.0	7.3	ND	7.4	58	1.1	0.27	0.33	110	30	30	ND	ND	ND
751222	1030	14.0	7.4	ND	11.2	51	2.0	0.18	0.18	30	30	ND	ND	ND	ND
760101	1157	14.7	7.4	ND	4.6	90	0.6	0.20	0.28	70	20	ND	ND	ND	ND
760108	105	13.0	7.5	2.7	15.4	73	4.3	0.81	0.48	ND	20	20	ND	ND	ND
760112	230	16.2	7.6	ND	11.8	101	0.8	0.43	0.48	20	20	ND	ND	ND	ND
760121	1215	13.0	7.7	ND	11.8	75	0.6	0.16	0.63	180	20	30	ND	ND	ND
760128	140	13.8	7.4	ND	12.4	115	1.3	0.16	0.50	20	20	ND	ND	ND	ND
760204	1045	14.5	7.7	0.3	12.0	148	0.7	0.09	0.24	30	ND	30	ND	ND	ND
760211	1050	14.5	7.3	ND	9.6	148	0.9	0.03	1.03	20	20	30	8	ND	ND
760218	1115	13.5	7.5	ND	9.4	160	0.9	0.14	0.45	20	20	30	14	ND	ND
760225	1225	14.8	7.0	ND	8.6	160	2.8	0.85	1.43	100	ND	30	10	7	ND
760303	1150	20.2	7.4	2.1	8.0	275	2.7	0.51	1.90	60	ND	15	ND	5	ND
760310	1150	16.4	7.3	1.7	10.2	193	3.2	0.89	1.90	28	15	13	ND	5	70
760315	115	19.5	7.5	1.4	9.8	38	2.7	0.81	0.81	120	15	20	ND	ND	ND
760324	200	19.0	7.6	0.6	9.4	163	1.7	0.11	0.14	135	ND	30	ND	ND	ND
760331	100	20.0	7.7	ND	10.0	225	1.0	0.14	0.48	78	11	15	5	ND	ND
760407	1200	18.8	7.2	1.0	9.8	188	1.0	0.29	0.60	56	16	30	5	ND	ND
760414	400	28.8	7.6	ND	10.2	36	1.2	0.19	0.43	214	20	25	6	ND	ND
760421	1000	17.2	7.3	3.5	11.4	1325	4.9	0.34	2.60	64	18	25	8	ND	ND
760510	1155	23.5	7.7	0.7	15.6	275	1.6	0.33	0.60	155	10	25	6	ND	ND
760526	1110	21.7	7.5	ND	12.6	613	2.1	0.65	1.83	73	16	15	8	5	ND
760609	1115	21.6	8.0	ND	11.2	200	1.0	0.51	1.00	220	13	30	10	11	50
760624	225	26.9	7.5	3.6	6.4	288	6.3	1.80	3.80	205	14	16	ND	ND	ND
760707	1155	24.4	7.6	0.6	11.6	169	2.2	0.65	1.30	120	14	20	ND	9	ND
760722	110	23.1	7.1	ND	12.8	187	1.3	0.57	0.95	110	30	46	ND	5	ND
760805	130	30.7	7.6	ND	9.8	281	1.4	0.30	0.55	400	20	24	4	ND	ND
760831	1135	26.5	7.7	ND	12.2	156	0.6	0.10	0.15	162	10	20	ND	ND	ND
760916	1145	25.8	7.4	ND	15.0	153	0.7	0.13	0.13	84	13	13	5	5	ND
760928	100	20.9	7.5	ND	10.2	150	0.8	0.13	0.23	112	14	20	ND	6	50
761019	1248	7.0	7.7	ND	13.2	73	0.7	0.07	0.76	82	31	20	5	ND	ND
761103	1230	20.4	7.5	ND	8.2	113	-	0.30	0.37	65	20	26	5	10	ND
761111	120	17.4	7.6	ND	8.8	143	0.4	0.32	0.58	170	20	26	7	ND	ND
Mean		18.8	7.5	0.5	10.6	183	1.7	0.36	0.79	98	17	22	< 4	< 5	< 50
Maximum		30.7	8.0	3.6	15.6	1325	6.3	1.80	3.80	400	31	110	14	11	70
Minimum		12.5	7.0	< 0.3	4.6	18	0.4	< 0.01	0.13	< 10	<10	<10	< 4	< 5	< 50
Standard deviation		4.9	0.2	1.0	2.4	224	1.3	0.35	0.78	79	9	19	4	3	16

[a] Year, month, day
[b] Not detectable

TABLE 15. CHEMICAL ANALYSIS OF WATER SAMPLES FROM NOVEMBER 18, 1975 TO NOVEMBER 11, 1976 TAKEN FROM SEEPAGE CREEK NO. 2 LOCATED ON THE CONCHO RIVER ADJACENT TO THE SAN ANGELO SEWAGE FARM

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
751118[a]	150	21.5	7.9	ND[b]	10.5	ND	ND	0.02	0.05	40	ND	ND	ND	ND	ND
751125	1245	20.0	7.1	ND	10.5	ND	0.4	0.05	0.05	30	ND	ND	ND	ND	ND
751202	215	20.0	7.1	ND	13.6	5	ND	0.04	0.05	20	ND	ND	ND	ND	ND
751209	1245	20.0	7.1	ND	14.8	5	0.4	0.04	0.06	70	30	ND	ND	ND	ND
751216	1225	19.9	7.2	ND	12.0	ND	ND	0.04	0.06	60	40	30	ND	ND	ND
751222	1104	19.7	7.7	ND	16.2	ND	1.2	0.04	0.04	20	20	ND	ND	ND	ND
760101	1245	20.0	7.1	ND	16.2	ND	0.3	0.05	0.05	10	ND	ND	ND	ND	ND
760108	200	19.0	7.0	ND	30.0	ND	ND	0.06	0.06	20	30	ND	ND	ND	ND
760112	310	19.5	7.2	ND	17.0	ND	ND	0.05	0.05	30	ND	40	ND	ND	ND
760121	125	19.7	7.3	ND	10.6	8	ND	0.06	0.07	40	ND	20	ND	ND	ND
760128	215	19.5	7.6	ND	18.4	ND	0.3	0.06	0.06	20	20	ND	ND	ND	ND
760204	1130	19.0	7.4	ND	17.4	ND	ND	0.04	0.04	40	ND	ND	ND	ND	ND
760211	1135	18.8	7.3	ND	15.4	ND	ND	ND	0.04	20	ND	20	12	ND	ND
760218	1145	18.8	7.3	ND	16.5	ND	0.4	0.05	0.05	10	30	ND	14	ND	ND
760225	100	17.8	7.0	ND	16.0	ND	ND	0.05	0.05	90	ND	20	6	7	ND
760303	1035	21.0	7.3	ND	14.0	5	ND	ND	ND	20	ND	ND	ND	ND	ND
760310	1050	18.4	7.3	ND	17.5	8	ND	0.05	0.05	10	ND	17	ND	ND	ND
760315	200	18.9	7.3	ND	16.0	ND	1.0	0.04	0.04	330	11	20	ND	ND	ND
760324	1245	18.4	7.4	ND	15.5	6	ND	0.03	0.03	80	19	15	ND	ND	ND
760331	1230	18.5	7.2	ND	14.0	13	ND	0.03	0.03	120	ND	10	ND	ND	ND
760407	100	19.0	7.0	ND	15.5	ND	ND	0.04	0.04	96	ND	20	ND	ND	ND
760414	330	19.3	7.2	ND	15.5	5	ND	0.04	0.04	188	18	25	5	ND	ND
760421	1015	18.2	7.1	ND	15.0	7	0.3	0.04	0.04	66	18	20	6	ND	ND
760510	1140	18.0	7.3	ND	15.0	6	0.3	0.03	0.03	150	10	25	6	ND	ND
760526	1215	18.4	7.6	ND	14.5	16	ND	0.06	0.07	108	ND	15	7	ND	ND
760609	120	18.9	7.5	ND	16.5	ND	0.3	0.05	0.05	315	10	20	5	ND	50
760624	310	18.4	7.1	ND	17.5	5	0.4	0.04	0.04	215	11	15	ND	ND	ND
760707	130	19.6	7.3	ND	18.0	5	0.4	0.02	0.02	315	17	16	ND	ND	ND
760722	220	19.6	7.2	ND	21.0	9	ND	0.03	0.03	175	32	37	ND	ND	ND
760805	220	19.5	7.4	ND	14.5	6	0.4	0.04	0.04	350	14	24	ND	ND	ND
760831	1215	19.3	7.5	ND	20.0	ND	ND	0.03	0.03	222	10	10	ND	ND	ND
760916	1245	19.7	7.2	ND	20.5	10	0.4	0.02	0.02	163	13	ND	ND	ND	ND
760928	1246	19.8	7.1	ND	16.0	6	0.5	0.01	0.01	75	14	17	ND	ND	ND
761019	1235	20.8	7.2	ND	20.0	6	0.6	0.04	0.04	68	ND	20	5	ND	ND
761103	1145	19.0	7.5	ND	19.0	7	ND	0.01	0.01	54	20	23	ND	ND	ND
761111	1240	20.0	7.1	ND	16.5	ND	ND	ND	ND	140	10	20	5	ND	ND
Mean		19.3	7.3	< 0.3	16.3	< 5	< 0.3	0.04	0.04	105	11	14	< 4	< 5	< 50
Maximum		21.5	7.9	< 0.3	30.0	16	1.2	0.06	0.07	350	40	40	14	7	50
Minimum		17.8	7.0	< 0.3	10.5	< 5	< 0.3	< 0.01	< 0.01	10	< 10	< 10	< 4	< 5	< 50
Standard deviation		0.8	0.2	0	3.5	4	0.3	0.02	0.02	100	11	11	4	1	8

[a] Year, month, day
[b] Not detectable

TABLE 16. CHEMICAL ANALYSIS OF WATER SAMPLES FROM NOVEMBER 18, 1975 to NOVEMBER 11, 1976 TAKEN FROM SEEPAGE CREEK NO. 3 LOCATED ON PRIVATE LAND ON THE CONCHO RIVER ADJACENT TO THE SAN ANGELO SEWAGE FARM

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
751118[a]	1035	19.5	7.1	ND[b]	17.6	9	ND	0.02	0.02	40	20	ND	ND	ND	ND
751125	940	18.5	7.1	ND	13.6	ND	0.4	0.03	0.03	50	ND	ND	ND	ND	ND
751202	1040	19.0	7.2	ND	17.0	5	ND	0.02	0.02	50	30	20	ND	ND	ND
751209	1015	19.0	7.4	ND	20.8	5	0.4	0.03	0.03	90	40	ND	ND	ND	ND
751216	945	18.2	7.1	ND	15.2	ND	ND	0.03	0.03	60	50	20	ND	ND	ND
751222	920	18.0	7.2	ND	19.4	ND	1.2	0.03	0.03	60	30	ND	ND	ND	ND
760101	1050	18.9	7.1	ND	20.5	ND	0.5	0.04	0.04	20	ND	ND	ND	ND	ND
760108	1125	18.6	7.0	ND	6.0	ND	ND	0.02	0.03	40	ND	20	ND	ND	ND
760112	115	18.0	7.2	ND	24.0	ND	ND	0.02	0.04	60	ND	20	ND	ND	ND
760121	1040	18.8	7.3	ND	24.5	5	ND	0.03	0.04	100	ND	20	ND	ND	ND
760128	1140	18.8	7.0	ND	22.5	ND	ND	0.04	0.04	150	20	ND	ND	ND	ND
760204	935	19.0	7.6	ND	20.0	ND	ND	0.02	0.02	90	ND	ND	ND	ND	ND
760211	920	19.0	7.2	ND	21.5	ND	0.5	0.02	0.02	130	20	20	12	ND	ND
760218	945	19.0	7.4	ND	22.5	ND	0.4	0.03	0.03	20	20	ND	12	ND	ND
760225	1000	18.9	7.0	ND	20.5	ND	0.5	0.03	0.07	70	ND	20	8	6	ND
760303	950	19.0	7.1	ND	21.0	ND	ND	0.02	0.02	20	ND	10	ND	ND	ND
760310	1005	19.0	7.4	ND	24.5	ND	ND	0.02	0.04	58	11	10	ND	ND	ND
760315	1050	19.9	7.4	ND	20.5	6	ND	0.05	0.05	99	ND	ND	5	ND	ND
760324	930	18.2	7.3	ND	22.5	ND	0.3	ND	ND	69	ND	20	5	ND	ND
760331	1015	18.5	7.1	ND	22.5	10	ND	0.05	0.05	120	11	15	5	ND	ND
760407	1030	18.1	7.0	ND	24.0	7	ND	0.02	0.02	35	10	25	5	ND	ND
760414	200	20.2	7.1	ND	22.5	8	ND	0.03	0.03	119	18	20	5	ND	ND
760421	905	18.8	7.2	ND	23.0	9	ND	0.03	0.03	23	10	20	12	ND	ND
760510	900	19.0	7.7	ND	21.5	9	0.4	0.03	0.03	97	10	25	8	ND	ND
760526	955	18.0	7.6	ND	25.0	6	ND	0.04	0.04	60	ND	25	10	ND	ND
760609	935	19.1	7.5	ND	24.0	5	0.3	0.03	0.06	135	ND	30	5	ND	ND
760624	1050	19.0	7.2	ND	24.5	ND	ND	ND	0.03	71	17	16	ND	ND	ND
760707	1030	19.5	7.5	ND	22.5	5	ND	0.01	0.01	77	14	20	ND	5	ND
760722	1050	19.6	7.5	ND	23.5	9	ND	0.02	0.02	45	50	37	ND	ND	ND
760805	1030	19.4	7.1	ND	20.0	6	ND	0.03	0.05	115	14	15	4	ND	ND
760831	1000	19.8	7.5	ND	23.0	5	ND	0.02	0.03	84	ND	13	ND	ND	ND
760916	1000	19.6	7.1	ND	21.0	12	0.4	ND	ND	44	13	10	ND	ND	ND
760928	1051	19.2	7.2	ND	19.0	6	ND	ND	ND	55	18	10	ND	ND	ND
761019	1042	18.9	7.0	ND	25.5	6	0.4	0.01	0.01	77	ND	17	6	ND	ND
761103	940	19.3	7.1	ND	19.0	7	0.5	0.01	0.01	31	17	26	ND	ND	ND
761111	1050	18.8	7.3	ND	21.5	ND	ND	ND	ND	96	10	20	7	ND	ND
Mean		18.9	7.2	<0.3	21.0	< 5	<0.3	0.02	0.03	71	13	15	<4	<5	<50
Maximum		20.2	7.7	<0.3	25.5	12	1.2	0.05	0.07	150	50	37	12	6	<50
Minimum		18.0	7.0	<0.3	6.0	< 5	<0.3	<0.01	<0.01	20	<10	<10	< 4	<5	<50
Standard deviation		0.5	0.2	0	3.7	4	0.3	0.01	0.02	35	14	10	4	1	0

[a] Year, month, day
[b] Not detectable

TABLE 17. CHEMICAL ANALYSIS OF WATER SAMPLES FROM NOVEMBER 18, 1975 TO NOVEMBER 11, 1976 TAKEN FROM CONCHO RIVER SAMPLING SITE NO. 1 LOCATED UPSTREAM FROM THE SAN ANGELO SEWAGE FARM

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		ug/ml	µg/ml	ng/ml		µg/ml				ng/ml			
751118[b]	945	16.5	8.1	ND[c]	1.0	19	0.5	ND	0.06	40	130	40	ND	ND	ND
751125	815	9.5	8.2	ND	2.4	18	0.4	0.03	0.06	50	20	ND	ND	20	ND
751202	920	9.5	8.1	ND	2.6	28	0.6	0.02	0.09	30	ND	40	ND	ND	ND
751209	830	10.0	8.1	ND	2.4	15	0.7	0.01	0.01	70	50	20	ND	ND	ND
751216	840	9.3	8.2	ND	1.9	14	0.4	0.02	0.06	80	40	ND	ND	ND	ND
751222	750	8.7	8.2	ND	2.8	19	1.7	0.02	0.03	30	20	ND	ND	ND	ND
760101	940	8.0	8.2	0.3	2.1	25	0.8	0.01	0.05	10	30	ND	ND	ND	ND
760108	1030	4.0	8.1	ND	4.8	25	ND	0.02	0.05	20	30	ND	ND	ND	ND
760112	1030	6.7	8.0	ND	2.8	20	0.5	ND	0.06	30	ND	30	ND	ND	ND
760121	940	7.5	8.2	ND	2.6	23	0.3	0.01	0.08	120	20	ND	ND	ND	ND
760128	1045	8.2	8.1	ND	1.6	25	0.5	0.03	0.05	10	20	ND	ND	ND	ND
760204	845	10.0	8.2	0.7	2.0	18	1.1	0.02	0.05	90	30	ND	ND	ND	ND
760211	830	13.0	8.2	ND	1.9	20	0.8	0.02	0.07	30	20	ND	ND	ND	ND
760218	825	13.0	8.2	ND	1.5	25	0.7	0.06	0.06	20	20	ND	ND	ND	ND
760225	845	10.7	7.9	ND	2.8	34	0.6	0.02	0.06	80	ND	ND	ND	ND	ND
760303	840	18.8	8.1	ND	2.5	28	ND	ND	0.05	10	ND	ND	ND	ND	70
760310	850	13.8	8.2	ND	1.3	34	0.6	0.02	0.07	23	15	13	ND	ND	ND
760315	935	14.0	8.1	ND	1.3	26	1.0	0.03	0.04	10	ND	ND	ND	ND	ND
760324	815	15.3	8.0	ND	1.3	28	0.3	0.03	0.03	12	21	ND	ND	ND	ND
760331	840	14.2	8.0	ND	1.3	48	0.4	0.01	0.06	35	11	ND	ND	ND	ND
760407	915	18.0	8.1	ND	0.8	31	0.6	0.02	0.07	24	32	15	ND	ND	ND
760414	930	21.2	8.1	ND	0.9	43	0.6	0.02	0.14	64	12	ND	ND	ND	ND
760421	805	19.4	8.4	ND	0.7	14	0.4	0.02	0.12	29	18	10	5	ND	ND
760510	745	18.5	8.2	ND	0.6	18	0.8	0.02	0.07	76	21	20	5	ND	ND
760526	240	28.0	8.3	ND	0.7	71	1.1	0.01	0.09	380	ND	ND	5	ND	ND
760609	825	25.2	8.1	ND	0.6	26	0.8	0.01	0.10	63	10	15	5	ND	ND
760624	925	28.0	8.4	ND	0.8	44	1.7	ND	0.10	27	17	ND	ND	ND	ND
760707	845	27.0	8.0	ND	0.3	15	0.9	0.03	0.04	24	ND	ND	ND	ND	ND
760722	915	26.4	7.9	ND	0.7	30	0.6	0.04	0.04	30	66	87	ND	ND	ND
760805	900	28.0	8.0	ND	0.9	28	0.4	ND	0.08	42	14	ND	5	ND	ND
760831	830	25.3	8.2	ND	0.8	25	1.0	0.01	0.03	32	ND	ND	ND	ND	ND
760916	830	26.0	7.8	ND	0.8	32	0.5	0.01	0.01	22	10	ND	ND	ND	ND
760928	934	21.7	7.8	1.0	0.9	26	0.8	ND	0.03	19	12	ND	ND	5	ND
761019	932	15.9	7.8	ND	1.5	22	0.8	0.01	0.06	23	ND	ND	ND	ND	ND
761103	822	13.3	7.8	ND	1.1	20	0.5	0.01	0.04	18	23	10	ND	ND	ND
761111	900	15.0	8.2	ND	1.4	16	0.6	0.01	0.02	40	ND	10	ND	ND	ND
Mean		15.8	8.1	<0.3	1.6[a]	27	0.7	0.017	0.060	48	20	<10	<4.0	<5.0	<50
Maximum		28.0	8.4	1.0	4.8	71	1.7	0.060	0.140	380	130	87	5.0	20.0	70
Minimum		4.0	7.8	<0.3	0.3	14	<0.3	<0.010	<0.010	10	<10	<10	<4.0	<5.0	<50
Standard Deviation		7.0	0.2	0.2	0.9	11	0.4	0.013	0.029	63	24	18	1.8	3.4	12

[a] Significantly different from downstream water samples

[b] Year, month, day

[c] Not detectable

TABLE 18. CHEMICAL ANALYSIS OF WATER SAMPLES FROM NOVEMBER 18, 1975 TO NOVEMBER 11, 1976 TAKEN FROM CONCHO RIVER SAMPLING SITE NO. 2 LOCATED DOWNSTREAM FROM THE SAN ANGELO SEWAGE FARM

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
751118[b]	310	18.0	8.0	ND[c]	3.9	24	ND	0.02	0.06	40	20	20	ND	ND	ND
751125	115	12.0	7.9	ND	6.0	33	0.6	0.02	0.06	50	ND	20	ND	ND	ND
751202	150	13.0	8.0	ND	6.6	38	0.6	0.19	0.19	60	40	ND	ND	ND	ND
751209	130	13.0	8.0	ND	6.0	16	0.6	ND	0.10	80	30	ND	ND	ND	ND
751216	1240	13.0	8.2	ND	5.7	19	0.5	0.02	0.06	60	30	ND	ND	ND	ND
751222	1117	10.0	8.0	ND	7.3	23	1.3	0.01	0.04	40	ND	ND	ND	10	ND
760101	100	10.9	7.9	ND	6.3	29	0.5	0.01	0.06	20	ND	ND	ND	ND	ND
760108	215	7.2	8.0	ND	14.0	31	0.5	0.05	0.06	20	ND	ND	ND	ND	ND
760112	325	10.9	7.9	ND	8.2	31	0.7	0.01	0.14	30	ND	20	ND	ND	ND
760121	140	10.8	8.1	ND	8.2	31	0.7	0.01	0.14	50	20	ND	ND	ND	ND
760128	230	11.0	8.2	ND	5.6	24	0.6	0.02	0.07	20	30	ND	ND	ND	ND
760204	1145	13.0	8.1	ND	6.6	25	0.9	0.02	0.06	40	20	ND	ND	ND	ND
760211	1215	15.0	8.0	ND	6.0	31	0.9	0.02	0.08	40	ND	ND	ND	ND	ND
760218	1220	16.5	7.9	ND	5.1	38	0.8	0.02	0.07	20	ND	ND	8	ND	ND
760225	120	14.8	7.9	ND	6.3	45	0.6	0.05	0.06	110	ND	ND	ND	ND	ND
760303	1205	21.0	7.8	ND	5.8	50	ND	0.03	0.08	90	ND	ND	ND	5	ND
760310	1205	16.2	8.0	0.4	6.5	59	0.6	0.03	0.07	119	ND	ND	ND	ND	ND
760315	205	17.1	8.1	ND	5.9	44	1.4	0.05	0.05	290	ND	20	ND	5	ND
760324	1115	17.8	7.9	ND	6.3	50	1.0	0.02	0.03	60	11	ND	5	ND	ND
760331	1145	16.9	8.0	ND	6.1	80	0.7	0.03	0.09	125	15	10	ND	ND	ND
760407	115	20.0	7.9	ND	5.3	50	0.5	0.02	0.08	157	15	15	ND	ND	ND
760414	345	25.0	8.0	ND	3.4	78	0.7	0.03	0.11	215	15	15	ND	ND	ND
760421	1030	20.6	8.2	ND	5.1	75	0.7	0.02	0.18	89	13	15	5	ND	ND
760510	1045	19.9	8.1	ND	3.4	80	0.9	0.02	0.14	185	13	20	12	ND	ND
760526	125	25.8	8.2	ND	4.3	185	1.0	0.03	0.10	150	10	ND	5	ND	ND
760609	135	26.9	8.1	ND	5.0	75	1.8	0.01	0.12	235	10	20	10	7	ND
760624	325	27.4	8.0	ND	7.1	120	1.7	ND	0.12	275	19	10	ND	ND	ND
760707	155	28.8	7.8	0.3	3.1	45	1.0	0.01	0.05	200	12	10	ND	ND	ND
760722	235	26.4	7.9	ND	3.6	65	0.9	0.02	0.05	140	20	24	7	5	ND
760805	240	30.8	8.1	ND	6.3	93	0.3	ND	0.06	500	17	19	ND	ND	ND
760831	1245	26.6	8.0	ND	3.5	30	ND	0.01	0.03	236	10	ND	ND	ND	ND
760916	100	27.2	7.8	ND	4.5	56	0.6	ND	0.03	181	16	ND	ND	ND	ND
760928	110	22.1	7.9	0.7	4.5	60	0.7	ND	0.05	95	18	ND	ND	5	ND
761019	100	17.2	7.7	ND	5.4	29	0.9	0.02	0.04	82	11	ND	5	ND	ND
761103	1255	17.8	7.9	ND	3.9	24	ND	0.04	0.07	102	15	ND	ND	ND	ND
761111	135	15.8	7.9	ND	5.1	33	0.4	0.01	0.01	210	ND	14	ND	ND	ND
Mean		18.2	8.0	<0.3	5.7[a]	51	0.7	0.024	0.078	123	12	<10	< 4.0	< 5.0	<50
Maximum		30.8	8.2	0.7	14.0	185	1.8	0.190	0.190	500	40	24	12.0	10.0	<50
Minimum		7.2	7.7	<0.3	3.1	16	<0.3	< 0.010	0.010	20	<10	<10	<4.0	<5.0	<50
Standard Deviation		6.3	0.1	0.1	2.0	33	0.4	0.031	0.042	101	11	9	3.2	2.5	ND

[a] Significantly different from upstream water samples.

[b] Year, month, day

[c] Not detectable

TABLE 19. CHEMICAL ANALYSIS OF WATER SAMPLES FROM DOMESTIC DEEP WELLS AND SHALLOW GROUND WELLS AT THE SEWAGE FARM

Date	Time	Temp.	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Shallow Ground Well - Location No. 8															
751118[a]	230	18.5	7.4	ND[b]	6.2	26	1.5	0.04	0.59	50	20	ND	ND	ND	ND
751125	1055	16.0	7.3	ND	8.4	8	0.7	ND	0.22	280	230	ND	ND	ND	ND
751202	1200	16.5	7.6	ND	1.7	5	ND	0.01	0.14	500	100	20	10	20	150
751209	1120	15.5	7.6	ND	1.1	8	0.5	0.01	0.01	200	120	20	ND	ND	ND
751216	1105	15.0	7.3	ND	0.8	ND	ND	0.01	0.19	150	120	30	ND	ND	ND
751222	1005	14.5	7.2	ND	4.4	28	1.2	0.01	0.30	90	90	ND	ND	ND	ND
760101	1138	14.1	7.5	ND	0.9	ND	0.7	0.04	0.08	110	70	40	ND	ND	ND
760108	1240	12.3	7.5	ND	1.3	10	ND	ND	0.07	30	30	20	ND	ND	ND
760112	150	13.7	7.4	ND	0.2	13	ND	0.02	0.03	120	80	30	ND	ND	ND
760121	1145	12.2	7.8	ND	0.7	6	ND	ND	0.06	240	120	ND	ND	ND	ND
760128	115	13.2	8.1	ND	0.7	ND	ND	0.02	0.07	250	100	ND	ND	ND	ND
760204	1025	11.3	7.7	ND	0.5	ND	ND	0.02	0.04	200	50	ND	ND	ND	ND
760211	1020	13.5	7.5	ND	1.9	17	ND	0.02	0.20	240	140	20	6	ND	ND
760218	1045	14.0	7.6	ND	0.2	ND	0.4	0.01	0.02	70	80	ND	12	8	ND
760225	1055	12.3	7.4	ND	0.3	ND	ND	0.01	0.02	140	70	20	7	6	ND
760303	1120	16.4	7.4	ND	0.1	5	ND	0.02	0.03	120	210	ND	ND	ND	ND
760310	1120	16.6	7.2	ND	1.5	725	ND	ND	0.08	228	145	ND	ND	ND	ND
760315	1205	16.5	7.4	ND	0.9	20	ND	0.04	0.04	160	120	25	ND	ND	ND
760324	115	17.2	7.1	ND	3.4	363	0.3	0.03	0.03	235	70	10	5	ND	ND
760331	130	16.0	7.2	ND	2.8	40	ND	0.02	0.02	275	212	10	5	ND	ND
760407	1130	16.6	7.1	ND	3.0	88	ND	0.02	0.05	155	150	25	6	ND	ND
760414	1030	23.1	7.0	ND	12.8	43	ND	0.03	0.03	105	36	25	5	ND	ND
760421	945	16.8	7.3	ND	4.6	700	ND	0.02	0.02	165	340	20	8	ND	ND
760510	1220	19.7	7.0	ND	0.8	125	ND	0.03	0.03	355	177	25	8	ND	ND
760521	1050	21.9	7.9	ND	6.7	575	0.7	0.03	0.04	195	165	25	10	ND	ND
760609	1050	20.4	7.7	ND	2.2	150	0.7	0.02	0.04	295	280	20	6	ND	ND
760624	155	21.8	7.3	ND	2.2	215	ND	ND	0.03	341	242	18	ND	ND	ND
760707	1140	23.9	7.6	ND	6.9	323	0.3	0.01	0.01	255	275	16	ND	ND	ND
760722	1245	23.2	7.1	ND	6.4	537	ND	0.02	0.02	220	102	46	ND	ND	ND
760805	105	22.0	7.2	ND	4.2	75	ND	ND	0.02	470	110	19	5	ND	ND
760831	1115	23.0	7.7	ND	0.6	10	ND	ND	0.02	286	158	13	ND	ND	ND
760916	1130	25.3	7.5	0.6	0.5	20	ND	ND	ND	166	92	10	ND	ND	ND
760928	1152	22.0	7.6	1.0	0.3	15	1.3	ND	ND	190	230	10	ND	ND	ND
761019	1137	17.9	7.1	ND	2.2	111	ND	0.01	0.01	157	120	20	8	ND	ND
761103	1115	17.0	7.5	ND	2.1	75	0.7	0.02	0.02	48	120	26	ND	ND	ND
761111	100	15.3	7.3	ND	4.1	78	ND	0.01	0.01	352	116	20	5	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. *(continued)*

Date	Time	Temp.	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Shallow Ground Well - Location No. 17															
751118[a]	245	18.5	6.9	ND[b]	8.1	25	ND	0.08	0.09	60	40	ND	ND	10	ND
751125	1110	16.2	7.3	ND	9.2	25	0.7	0.10	0.35	240	230	40	10	ND	ND
751202	1220	15.5	7.7	ND	2.6	10	1.1	0.04	0.07	10	ND	ND	ND	ND	ND
751209	1135	16.0	7.1	ND	12.7	10	0.3	0.06	0.07	270	140	ND	ND	ND	ND
751216	1120	15.1	7.7	ND	11.8	14	0.4	0.05	0.08	130	280	20	ND	ND	ND
751222	1021	15.0	7.0	ND	13.8	23	1.1	0.04	0.04	50	100	ND	ND	ND	ND
760101	1147	16.0	7.2	ND	9.2	20	0.7	0.05	0.24	210	310	20	ND	ND	ND
760108	115	13.2	7.7	ND	14.4	33	1.0	0.06	0.15	70	40	ND	ND	ND	ND
760112	220	16.1	7.5	ND	6.2	36	0.5	0.01	0.05	120	100	30	ND	ND	ND
760121	1200	14.6	8.0	ND	2.0	8	ND	0.03	0.04	190	60	ND	ND	ND	ND
760128	130	19.2	7.6	ND	4.9	9	0.3	0.02	0.04	270	100	ND	ND	ND	ND
760204	1035	15.6	7.5	ND	8.6	28	ND	0.03	0.05	110	190	20	ND	ND	ND
760211	1035	16.1	7.4	ND	5.5	26	0.5	0.03	0.16	180	340	20	8	8	ND
760218	1100	11.2	7.2	ND	4.0	37	1.3	0.02	0.03	50	60	ND	ND	ND	ND
760225	1110	15.3	7.4	ND	5.0	21	ND	0.01	0.03	100	60	ND	8	6	ND
760303	1135	18.8	7.1	ND	5.5	250	ND	ND	0.02	80	60	10	ND	5	ND
760310	1135	16.6	7.1	ND	10.8	46	ND	0.02	0.04	156	94	ND	ND	ND	ND
760315	100	16.8	7.2	ND	10.0	10	1.1	0.02	0.02	210	290	10	ND	ND	ND
760324	100	17.3	7.1	ND	2.6	50	ND	0.03	0.03	165	92	20	ND	ND	ND
760331	115	19.3	7.1	ND	11.1	63	ND	0.01	0.01	125	162	10	6	ND	ND
760407	1145	18.0	7.1	ND	10.2	60	ND	0.05	0.05	112	125	25	6	ND	ND
760414	1100	23.5	7.2	ND	12.6	50	ND	0.06	0.15	140	71	25	6	ND	ND
760421	955	18.3	7.1	ND	11.4	75	0.4	0.05	0.08	180	350	25	8	ND	ND
760510	1205	20.0	7.1	ND	8.8	300	ND	0.05	0.05	340	238	25	6	ND	70
760526	1100	19.8	7.6	ND	14.0	238	ND	0.04	0.04	180	190	38	12	ND	ND
760609	1105	21.0	7.5	ND	12.2	350	ND	0.03	0.07	225	195	15	6	ND	ND
760624	215	21.9	7.0	ND	13.8	350	0.3	0.01	0.09	325	347	22	14	ND	ND
760707	1210	22.9	7.3	ND	13.0	400	ND	0.03	0.03	225	115	20	ND	ND	ND
760722	100	22.0	7.2	ND	10.6	525	ND	0.05	0.05	190	130	46	5	ND	ND
760805	120	24.0	7.2	ND	10.0	388	0.5	0.02	0.04	480	160	24	4	ND	50
760831	1125	22.5	7.5	6.3	6.6	30	6.6	0.06	0.07	232	142	ND	ND	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Shallow Ground Well - Location No. 18															
751216[a]	110	19.0	7.4	ND[b]	0.8	5	0.6	0.05	0.05	180	310	20	ND	ND	ND
751222	1140	18.5	7.4	ND	1.4	8	1.4	0.09	0.09	60	90	ND	ND	ND	ND
760101	120	12.6	7.1	ND	0.7	20	0.5	0.10	0.12	70	110	20	ND	ND	ND
760108	230	12.0	7.0	ND	1.4	7	0.4	0.10	0.15	60	80	20	ND	ND	ND
760112	335	18.1	7.4	ND	0.7	13	0.4	0.13	0.14	90	130	40	ND	ND	ND
760121	155	11.8	7.3	ND	1.3	28	ND	0.15	0.15	110	100	ND	10	ND	ND
760128	300	16.5	7.0	ND	1.6	ND	0.3	0.11	0.13	120	90	ND	ND	ND	ND
760204	1200	16.8	7.6	ND	1.8	15	0.5	0.10	0.10	80	60	ND	ND	ND	ND
760211	1235	16.2	7.0	ND	0.9	11	0.4	0.09	0.09	110	160	ND	10	6	ND
760218	1235	18.5	7.0	ND	1.3	5	0.5	0.10	0.10	70	150	ND	ND	ND	ND
760225	135	17.6	7.0	ND	1.0	8	0.5	0.10	0.10	180	90	ND	ND	7	ND
760303	1220	17.8	7.1	ND	0.8	11	ND	.14	0.14	120	90	15	ND	ND	ND
760310	115	16.0	7.1	ND	10.8	47	ND	0.02	0.04	132	87	ND	ND	ND	ND
760315	230	16.3	7.1	ND	2.0	9	0.6	0.13	0.13	310	92	10	ND	ND	ND
760324	1015	16.8	7.2	ND	0.3	12	ND	0.09	0.09	125	140	15	ND	5	ND
760331	1100	16.5	7.0	ND	1.6	14	ND	0.08	0.08	225	173	15	5	ND	ND
760407	130	17.5	7.0	ND	0.8	13	ND	0.14	0.14	202	135	20	5	ND	ND
760414	1130	20.2	7.4	ND	0.8	29	1.0	0.16	0.17	275	234	25	9	ND	ND
760421	1045	17.5	7.3	ND	0.2	37	0.4	0.11	0.11	258	490	15	6	ND	ND
760510	950	17.3	7.6	ND	0.8	45	0.6	0.12	0.12	248	257	15	6	ND	ND
760526	145	19.0	7.2	ND	1.9	26	0.8	0.15	0.16	245	165	25	8	ND	ND
760609	150	19.2	7.3	ND	1.1	5	0.4	0.16	0.16	550	670	30	5	ND	ND
760624	340	19.7	7.1	ND	0.7	9	0.5	0.13	0.13	465	147	16	ND	ND	ND
760707	220	21.5	7.2	ND	1.1	9	ND	0.10	0.10	370	160	10	ND	ND	ND
760722	250	21.0	7.2	ND	2.1	8	ND	0.13	0.13	370	180	42	5	ND	ND
760805	255	20.1	7.0	ND	1.3	11	ND	0.11	0.11	650	102	15	ND	ND	ND
760831	100	19.8	7.4	ND	0.8	ND	ND	0.14	0.14	400	122	ND	ND	ND	ND
760916	115	21.6	7.0	ND	0.5	12	0.4	0.07	0.07	320	142	101	ND	ND	ND
760928	200	20.0	7.1	ND	0.5	14	ND	0.08	0.08	192	180	10	ND	ND	ND
761019	121	20.7	7.0	ND	1.3	11	ND	0.05	0.13	197	100	29	6	ND	ND
761103	115	20.0	7.0	ND	0.4	7	0.5	0.10	0.10	206	145	29	7	ND	ND
761111	150	18.5	7.0	ND	0.3	ND	ND	0.01	0.10	330	140	26	7	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Shallow Ground Well - Location No. 19															
751216[a]	120	19.0	7.1	ND[b]	1.6	ND	ND	0.03	0.03	150	170	30	ND	ND	ND
751222	1155	17.0	6.9	ND	4.0	ND	0.9	0.03	0.03	140	400	ND	ND	ND	ND
760101	125	16.3	7.0	ND	1.3	10	0.7	0.03	0.05	90	90	40	ND	ND	ND
760108	240	11.5	7.0	ND	2.3	5	ND	0.18	0.18	50	40	20	ND	ND	ND
760112	345	17.4	7.1	ND	0.8	9	ND	0.02	0.04	100	240	50	ND	ND	ND
760121	1200	14.6	7.2	ND	1.7	5	ND	0.04	0.04	120	150	ND	ND	10	ND
760128	310	16.0	7.0	ND	1.7	14	0.3	0.04	0.04	130	120	ND	ND	ND	ND
760204	1210	15.0	7.3	ND	1.5	ND	ND	ND	0.02	70	50	ND	ND	ND	ND
760211	1245	15.7	7.0	ND	1.6	ND	ND	0.02	0.03	110	100	ND	12	7	ND
760218	1245	18.7	7.0	ND	1.1	ND	0.4	0.02	0.02	60	60	20	ND	6	ND
760225	150	16.2	7.0	ND	1.2	ND	ND	0.02	0.02	150	70	20	9	7	ND
760303	1235	17.2	6.9	ND	1.1	5	ND	0.02	0.02	120	60	25	ND	5	ND
760310	130	17.7	7.0	ND	1.1	39	ND	0.03	0.07	218	83	10	ND	ND	ND
760315	245	16.8	7.0	ND	0.4	11	0.5	ND	ND	410	150	10	5	ND	ND
760324	1030	16.8	7.0	ND	0.4	6	ND	0.02	0.03	86	135	20	ND	ND	ND
760331	1110	16.2	7.0	ND	1.4	16	ND	0.01	0.01	130	200	20	6	ND	ND
760407	145	16.9	6.8	ND	1.5	7	ND	0.03	0.03	257	157	25	5	ND	ND
760414	1145	21.2	7.2	ND	2.0	11	ND	0.02	0.02	215	74	25	6	ND	ND
760421	1050	16.8	7.0	ND	2.2	15	ND	0.03	0.03	270	420	20	6	ND	ND
760510	1000	17.0	7.3	ND	2.4	43	0.4	0.04	0.04	247	210	20	6	ND	ND
760526	1155	18.2	7.4	ND	3.7	10	ND	0.03	0.03	170	125	38	12	ND	ND
760609	200	17.7	7.0	ND	3.9	6	ND	0.04	0.05	580	400	35	6	ND	ND
760624	350	18.4	7.0	ND	4.2	14	ND	0.02	0.02	475	312	18	8	ND	ND
760707	230	20.1	7.2	ND	2.9	9	ND	0.03	0.03	435	150	16	ND	ND	ND
760722	305	21.0	7.0	ND	4.7	12	ND	0.02	0.02	390	215	50	5	ND	ND
760805	310	21.7	7.0	ND	6.0	13	0.5	0.01	0.01	970	102	15	4	ND	ND
760831	115	19.2	7.0	ND	6.0	13	ND	0.03	0.03	446	122	ND	ND	ND	50
760916	130	20.3	7.0	ND	8.5	12	0.3	ND	0.01	273	142	13	ND	ND	ND
760928	205	19.9	7.0	ND	6.6	11	ND	0.01	0.01	181	180	ND	ND	ND	50
761019	130	20.3	7.0	ND	7.4	9	ND	0.03	0.05	187	100	26	6	ND	ND
761103	130	18.7	7.1	ND	1.4	19	0.5	0.18	0.18	246	145	35	11	6	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Shallow Ground Well - Location No. 20															
761111[a]	205	18.0	7.0	ND[b]	4.4	11	ND	0.01	0.01	525	140	26	8	ND	ND
751216	130	19.0	7.0	ND	4.4	11	0.3	0.02	0.02	180	190	20	ND	10	ND
751222	1200	19.0	6.9	ND	6.6	6	0.7	0.03	0.03	50	100	ND	ND	ND	ND
760101	130	18.6	7.0	ND	5.2	6	0.4	0.03	0.03	90	120	40	ND	ND	ND
760108	250	17.0	7.1	ND	7.2	8	ND	0.02	0.05	50	70	20	ND	ND	ND
760112	355	18.6	7.1	ND	5.1	5	ND	0.01	0.03	70	70	40	ND	ND	ND
760121	230	18.3	7.1	ND	4.8	8	ND	0.03	0.03	150	150	ND	ND	10	ND
760128	320	17.7	7.0	ND	4.9	ND	ND	0.02	0.02	190	170	ND	ND	ND	ND
760204	1220	18.0	7.3	ND	5.0	ND	0.5	ND	0.01	80	70	ND	ND	ND	ND
760211	1255	18.1	7.0	ND	4.3	ND	0.4	0.01	0.01	100	100	ND	12	8	ND
760218	100	17.9	7.0	ND	3.8	ND	0.4	0.03	0.03	80	130	20	8	6	ND
760225	155	19.2	6.9	ND	3.9	13	0.4	0.02	0.02	180	90	20	10	7	ND
760303	1250	19.1	7.0	ND	3.8	5	ND	ND	ND	120	60	25	ND	5	ND
760310	145	18.0	7.0	ND	4.1	8	ND	0.02	0.05	168	74	20	ND	ND	70
760315	310	19.8	7.1	ND	2.4	6	0.6	0.04	0.04	540	60	15	8	ND	ND
760324	1045	16.8	7.0	ND	0.7	7	ND	0.02	0.07	125	120	20	ND	5	ND
760331	1120	17.0	6.9	ND	4.2	13	ND	0.03	0.03	170	185	20	8	ND	ND
760407	200	18.7	6.8	ND	3.9	7	ND	0.02	0.02	275	120	40	6	ND	ND
760414	1200	20.4	7.0	ND	5.0	14	ND	0.02	0.02	178	36	30	6	ND	ND
760421	1055	15.9	7.0	ND	5.1	16	ND	0.04	0.04	270	350	30	11	ND	ND
760510	1010	16.8	7.0	ND	4.2	23	ND	0.04	0.04	235	210	20	6	ND	ND
760526	205	18.1	7.2	ND	8.0	16	ND	0.04	0.08	330	320	38	10	ND	ND
760609	210	17.9	7.0	ND	7.3	5	ND	0.04	0.07	515	235	35	ND	ND	ND
760624	400	18.0	7.0	ND	7.4	20	ND	ND	0.01	465	187	18	5	ND	ND
760707	245	22.1	7.0	ND	7.0	7	ND	0.01	0.01	600	120	20	ND	ND	ND
760722	320	19.8	7.0	ND	10.1	15	ND	0.02	0.02	340	81	42	5	ND	ND
760805	325	20.2	7.2	ND	6.8	21	ND	0.01	0.03	660	225	15	ND	ND	ND
760831	130	20.8	7.1	ND	10.0	6	ND	0.02	0.02	402	128	ND	ND	ND	ND
760916	145	20.1	7.0	ND	9.5	13	0.3	0.01	ND	360	104	16	ND	ND	50
760928	211	19.0	7.0	ND	7.6	10	ND	ND	0.03	235	166	10	ND	ND	ND
761019	133	20.9	7.0	ND	10.8	13	0.3	0.02	0.02	207	105	20	6	ND	ND
761103	145	20.0	7.3	ND	8.2	5	ND	0.03	0.07	216	110	20	11	ND	ND
761111	220	18.0	7.0	ND	7.6	ND	ND	ND	ND	365	175	26	8	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml		µg/ml	ng/ml					
Shallow Ground Well - Location no. 21															
751216[a]	140	18.0	7.0	ND[b]	10.2	6	ND	0.03	0.02	180	20	20	ND	20	ND
751222	1215	18.0	7.0	ND	12.0	6	1.0	0.03	0.03	40	50	ND	ND	ND	ND
760101	140	18.8	7.0	ND	8.4	6	0.5	0.02	0.03	70	70	40	ND	ND	ND
760108	300	18.5	7.3	ND	18.0	8	ND	ND	0.04	50	60	ND	ND	ND	ND
760112	405	18.1	7.1	ND	14.4	8	ND	0.02	0.03	100	130	30	ND	ND	ND
760121	250	17.7	7.3	ND	15.6	9	ND	0.02	0.03	110	70	ND	ND	10	ND
760128	345	17.8	7.1	ND	12.0	ND	0.3	0.02	0.02	120	100	ND	ND	ND	ND
760204	1230	18.0	7.2	ND	8.4	ND	ND	ND	0.02	70	50	ND	ND	ND	ND
760211	105	17.7	7.0	ND	11.2	ND	ND	0.01	0.01	100	110	20	12	u	ND
760218	115	18.8	7.3	ND	13.0	ND	0.7	0.02	0.02	80	120	20	6	6	ND
760225	210	18.6	7.0	ND	13.6	6	ND	0.02	0.02	170	60	30	8	8	ND
760303	105	21.2	7.0	ND	16.0	8	ND	ND	ND	140	70	25	ND	ND	70
760310	200	17.2	7.1	ND	8.8	8	ND	0.02	0.06	208	64	13	ND	ND	70
760315	325	17.2	7.1	ND	4.8	6	ND	ND	ND	740	90	10	ND	ND	ND
760324	1100	16.8	7.1	ND	8.2	ND	ND	0.01	0.01	115	115	20	ND	5	ND
760331	1130	16.8	7.2	ND	11.6	8	ND	0.03	0.03	125	150	15	8	ND	ND
760407	215	18.1	7.2	ND	12.2	9	ND	0.03	0.02	310	180	20	6	ND	ND
760414	1215	21.1	6.8	ND	12.2	20	ND	0.03	0.03	175	31	20	6	ND	ND
760421	1100	16.5	6.9	ND	13.2	15	ND	0.02	0.02	310	565	25	8	ND	ND
760510	1020	17.2	7.2	ND	15.6	16	0.7	0.04	0.04	210	225	15	6	ND	ND
760526	215	19.3	7.2	ND	17.4	31	ND	0.02	0.02	335	230	38	12	ND	ND
760609	220	18.9	7.2	ND	18.8	11	0.5	0.03	0.09	920	310	35	ND	ND	ND
760624	410	19.5	7.0	ND	15.0	6	ND	ND	0.02	465	222	18	6	ND	ND
760707	300	21.0	7.1	ND	16.0	36	ND	ND	ND	740	94	16	ND	ND	ND
760722	335	20.8	7.1	ND	17.4	238	0.6	0.02	0.02	500	150	42	7	ND	ND
760805	340	19.8	7.1	ND	10.8	ND	ND	0.01	0.02	710	295	29	ND	ND	ND
760831	145	19.7	7.1	ND	16.2	20	ND	0.02	0.10	400	78	ND	5	ND	ND
760916	200	20.5	7.1	ND	20.0	13	0.3	0.01	0.01	445	224	16	ND	ND	ND
760928	222	19.3	7.1	ND	16.5	24	0.4	ND	0.01	210	144	10	ND	ND	ND
761019	144	20.9	7.1	ND	25.0	14	1.5	0.03	0.04	402	94	20	8	ND	ND
761103	200	19.5	7.4	ND	11.0	5	ND	0.01	0.01	336	181	23	7	ND	ND
761111	235	16.6	7.2	ND	14.0	ND	ND	ND	ND	380	145	23	7	ND	ND
SHALLOW GROUND WELLS All Samples (N = 195)															
Mean		18.1	7.2	<0.3	5.8	49	< 0.3	0.04	0.06	233	149	17	<4	<5	<50
Maximum		25.3	8.1	6.3	25.0	725	6.6	0.18	0.59	970	670	50	14	20	150
Minimum		11.2	6.8	<0.3	0.1	< 5	< 0.3	<0.01	<0.01	10	< 10	<10	<4	<5	<50
Standard deviation		2.6	0.2	0.5	5.2	118	0.6	0.04	0.07	165	97	13	4	3	16

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp.	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Domestic Deep Well - Location No. 9															
751118[a]	1010	22.0	7.3	ND[b]	4.8	ND	1.1	ND	ND	120	50	40	ND	10	ND
751125	835	13.0	7.3	ND	9.3	ND	ND	ND	ND	120	ND	ND	ND	ND	ND
751202	945	19.0	7.3	ND	7.6	5	ND	ND	ND	100	60	40	ND	10	ND
751209	905	19.5	7.2	ND	9.0	5	ND	ND	ND	140	40	ND	ND	ND	ND
751216	900	18.5	7.4	ND	5.8	ND	0.4	0.01	0.02	90	30	ND	ND	ND	ND
751222	852	19.6	7.3	ND	11.2	ND	1.0	0.01	0.01	110	ND	ND	ND	ND	ND
760101	1004	21.0	7.2	ND	8.6	ND	0.3	0.02	0.03	60	20	170	ND	ND	ND
760108	1045	18.2	7.1	ND	14.0	5	ND	ND	ND	310	ND	ND	ND	ND	ND
760112	1230	17.2	7.4	ND	9.6	ND	ND	0.01	0.03	70	ND	30	ND	ND	ND
760121	955	8.3	7.7	ND	10.0	13	ND	0.03	0.04	120	20	20	ND	ND	ND
760128	1115	19.0	7.2	ND	9.4	ND	ND	0.02	0.02	140	20	ND	ND	ND	150
760204	915	19.0	7.4	ND	8.4	ND	ND	0.01	0.01	160	ND	ND	ND	ND	ND
760211	855	14.5	7.0	ND	8.6	11	0.5	ND	0.03	180	20	ND	10	ND	ND
760218	900	20.5	7.4	ND	8.4	ND	ND	0.03	0.03	70	30	ND	6	6	ND
760225	915	13.0	7.0	ND	8.0	ND	ND	ND	0.01	150	ND	ND	6	ND	ND
760303	910	20.3	7.3	ND	6.8	ND	ND	ND	ND	70	20	ND	ND	ND	ND
760310	920	14.0	7.3	ND	8.6	5	ND	ND	0.01	48	15	10	ND	ND	70
760315	1005	19.6	7.3	ND	7.8	ND	ND	0.02	0.02	117	15	15	5	ND	80
760324	900	21.5	7.2	ND	8.2	ND	ND	0.03	0.03	93	21	20	ND	ND	70
760407	930	16.8	7.1	ND	8.2	ND	ND	0.01	0.01	118	30	25	9	ND	ND
760414	1015	20.5	7.2	ND	8.8	5	ND	0.02	0.02	200	28	20	5	ND	ND
760421	855	19.0	7.6	ND	8.8	40	ND	0.02	0.02	175	13	20	6	ND	ND
760510	815	20.2	7.5	ND	8.0	9	0.3	ND	0.03	160	13	25	6	ND	70
760526	900	24.0	7.6	ND	9.6	6	ND	0.02	0.03	155	16	45	8	ND	ND
760609	840	25.0	7.6	ND	8.4	ND	ND	0.01	0.01	200	45	15	6	ND	50
760624	1000	25.4	7.4	ND	9.2	10	ND	ND	0.01	120	35	18	19	5	ND
760707	955	26.0	7.5	ND	7.4	ND	ND	0.02	0.02	140	30	16	ND	5	ND
760722	955	24.2	7.5	ND	10.8	5	ND	0.02	0.02	110	66	42	ND	ND	50
760805	1000	26.3	7.3	ND	8.2	ND	ND	0.01	0.01	250	40	24	8	ND	50
760831	930	25.0	7.4	ND	10.2	ND	ND	0.03	0.03	190	16	10	ND	ND	ND
760916	915	26.8	7.3	ND	10.8	12	0.3	ND	ND	180	34	10	ND	ND	ND
760928	1026	21.2	7.2	ND	8.6	8	0.3	ND	ND	262	30	17	ND	ND	ND
761019	1022	19.0	7.0	ND	14.4	8	ND	0.01	0.01	377	15	20	6	ND	ND
761103	915	20.5	7.2	ND	9.0	9	ND	ND	ND	66	24	20	ND	ND	ND
761111	1025	20.7	7.5	ND	10.4	5	ND	ND	ND	138	22	20	5	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Domestic Deep Well - Location No. 10															
751118[a]	1025	20.0	7.0	ND[b]	15.8	5	0.4	0.03	0.03	0.5	50	ND	ND	ND	ND
751125	920	18.5	6.9	ND	13.6	ND	ND	0.03	0.03	150.0	70	ND	ND	ND	ND
751202	1025	19.5	7.0	ND	15.4	5	ND	0.02	0.02	80.0	20	ND	ND	ND	ND
751209	1000	19.5	7.1	ND	18.0	5	0.3	0.04	0.04	270.0	20	ND	ND	ND	100
751216	935	19.2	7.0	ND	15.0	ND	ND	0.03	0.04	200.0	20	20	ND	ND	ND
751222	825	19.4	7.0	ND	22.0	ND	1.1	0.03	0.03	190.0	20	ND	ND	ND	ND
760101	1035	19.7	7.1	ND	21.0	5	0.3	0.02	0.05	280.0	20	20	ND	ND	ND
760108	1115	13.0	7.1	ND	22.0	8	ND	0.01	0.05	20.0	20	ND	ND	ND	ND
760112	105	19.5	7.2	ND	24.0	ND	ND	0.02	0.03	190.0	ND	40	ND	ND	ND
760121	1030	17.7	7.3	ND	21.5	11	ND	0.03	0.04	300.0	ND	20	ND	ND	ND
760204	925	19.1	7.3	ND	19.0	ND	ND	0.02	0.02	280.0	ND	ND	ND	ND	ND
760211	910	19.6	7.0	ND	21.0	ND	ND	0.02	0.03	300.0	ND	ND	6	ND	ND
760218	930	19.8	7.0	ND	23.5	ND	0.3	ND	0.01	180.0	ND	ND	10	6	ND
760225	945	19.2	7.0	ND	23.5	13	0.3	0.01	0.01	300.0	ND	20	10	ND	ND
760303	935	18.6	7.2	ND	24.0	10	ND	0.03	0.03	200.0	ND	10	ND	ND	ND
760310	950	19.2	7.2	ND	23.0	9	ND	0.02	0.02	241.0	24	10	ND	ND	ND
760315	1035	20.6	7.3	ND	23.0	ND	ND	0.03	0.03	350.0	ND	10	5	ND	ND
760324	915	19.0	7.0	ND	24.5	6	0.3	ND	ND	225.0	ND	10	5	ND	ND
760331	1000	19.5	7.2	ND	22.0	7	ND	0.01	0.01	240.0	ND	20	5	ND	ND
760407	1015	18.7	7.0	ND	24.5	9	ND	0.03	0.03	255.0	10	20	ND	ND	ND
760414	145	20.5	7.1	ND	25.0	11	ND	0.05	0.05	275.0	23	20	5	ND	ND
760421	900	19.3	7.0	ND	23.5	9	ND	0.04	0.04	145.0	13	20	8	ND	ND
760510	850	20.0	7.5	ND	19.0	11	ND	0.02	0.02	255.0	10	20	5	ND	ND
760526	940	21.0	7.2	ND	25.0	16	0.4	0.04	0.05	250.0	ND	25	8	ND	ND
760609	925	19.0	7.2	ND	23.5	8	ND	0.03	0.04	295.0	13	15	5	ND	50
760624	1035	20.8	7.2	ND	24.0	9	ND	ND	0.02	102.0	14	16	5	ND	ND
760707	1015	20.5	7.5	ND	23.0	5	ND	0.02	0.02	182.0	17	16	ND	5	ND
760722	1030	20.5	7.8	ND	27.0	7	ND	0.02	0.02	190.0	91	46	ND	ND	ND
760805	1015	21.1	7.2	ND	20.0	12	ND	0.02	0.02	225.0	22	19	4	ND	ND
760831	950	21.0	7.1	ND	26.0	ND	ND	0.02	0.02	162.0	19	10	ND	ND	ND
760916	940	21.7	7.1	ND	30.0	12	ND	ND	ND	163.0	ND	13	ND	ND	ND
760928	1044	19.8	7.1	ND	22.5	10	0.5	ND	ND	180.0	20	17	ND	ND	ND
761019	1032	19.1	7.2	ND	30.5	6	ND	0.01	0.01	147.0	ND	20	6	ND	ND
761103	920	19.0	7.1	ND	20.0	4	ND	0.01	0.01	123.0	17	25	5	ND	ND
761111	1040	19.0	7.0	ND	25.4	ND	ND	0.01	0.01	255.0	20	23	ND	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Domestic Deep Well - Location No. 11															
751118[a]	200	19.5	7.0	ND[b]	8.1	6	0.5	0.02	0.07	100	30	ND	ND	ND	ND
751125	1210	18.0	7.1	ND	9.6	ND	0.6	0.02	0.06	120	20	ND	ND	ND	ND
751202	130	19.0	7.0	ND	11.8	5	ND	0.02	0.02	80	40	ND	ND	ND	ND
751209	110	19.0	7.2	ND	12.0	5	ND	0.03	0.03	170	40	ND	ND	ND	ND
751216	1140	19.1	7.1	ND	8.8	ND	ND	0.03	0.03	80	40	30	ND	ND	ND
751222	1041	19.0	7.0	ND	13.6	ND	1.1	0.03	0.03	30	ND	ND	ND	ND	ND
760101	1210	19.1	7.0	ND	11.6	13	0.4	0.03	0.04	40	ND	ND	ND	ND	ND
760108	130	17.3	7.1	ND	18.6	7	ND	0.02	0.09	30	ND	20	ND	ND	ND
760112	245	19.8	7.2	ND	15.6	ND	ND	0.01	0.04	30	ND	30	ND	ND	ND
760121	1255	18.9	7.0	ND	15.6	8	ND	0.03	0.04	50	ND	20	ND	ND	ND
760128	155	18.8	7.1	ND	13.8	ND	0.3	0.04	0.04	60	20	ND	ND	ND	ND
760204	1100	19.5	7.3	ND	13.8	ND	0.4	0.03	0.03	90	ND	ND	ND	ND	ND
760211	1105	18.5	7.0	ND	13.0	ND	ND	0.03	0.03	10	ND	ND	11	ND	ND
760218	1130	18.5	7.1	ND	12.6	ND	0.4	0.02	0.02	30	ND	ND	14	6	ND
760225	1140	18.6	6.9	ND	12.2	ND	ND	0.02	0.02	100	ND	20	6	6	ND
760303	1105	19.8	7.0	ND	13.2	11	ND	0.01	0.02	80	ND	15	ND	ND	70
760310	1205	19.8	7.2	ND	14.2	8	ND	0.04	0.04	91	11	10	ND	ND	ND
760315	130	20.1	7.1	ND	12.6	8	ND	0.02	0.02	330	ND	10	ND	ND	ND
760324	1130	19.6	7.0	ND	13.6	8	ND	ND	ND	88	ND	10	ND	ND	ND
760331	1200	16.9	7.0	ND	13.6	11	ND	0.02	0.02	97	11	15	5	ND	ND
760407	1215	18.2	7.0	ND	14.4	ND	ND	0.04	0.04	81	22	25	5	ND	ND
760414	300	19.7	7.1	ND	15.0	6	ND	0.04	0.06	215	15	20	6	ND	ND
760421	1005	18.7	7.0	ND	14.2	17	ND	0.04	0.08	81	18	20	6	ND	ND
760510	1100	17.9	7.2	ND	17.8	11	ND	0.03	0.04	285	18	20	6	ND	ND
760526	1145	20.2	7.3	ND	16.4	29	ND	0.04	0.04	83	13	32	12	ND	ND
760609	1125	19.0	7.3	ND	15.8	9	ND	0.05	0.05	225	13	15	8	ND	ND
760624	240	19.8	7.1	ND	15.0	5	ND	0.01	0.01	215	17	16	ND	ND	ND
760707	1225	18.8	7.4	ND	14.0	ND	ND	0.01	0.01	182	17	10	ND	9	ND
760722	1230	19.0	7.2	ND	16.4	9	ND	0.02	0.02	88	30	37	ND	ND	ND
760805	145	19.8	7.1	ND	12.4	11	ND	0.02	0.02	380	25	15	4	ND	ND
760831	1230	19.0	7.3	ND	14.8	ND	ND	0.02	0.02	290	10	10	ND	ND	ND
760916	1200	19.8	7.0	ND	17.0	13	0.5	ND	ND	107	16	13	ND	ND	ND
760928	1202	19.3	7.3	ND	10.8	11	0.3	0.01	0.01	67	18	20	ND	ND	ND
761019	1152	18.8	7.1	ND	16.6	9	0.4	0.03	0.04	67	ND	20	5	ND	ND
761103	1200	19.5	7.0	ND	11.2	5	ND	0.02	0.03	63	20	20	9	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Domestic Deep Well - Location No. 12															
751118[a]	1100	20.0	7.1	ND[b]	10.8	5	ND	0.03	0.03	20	ND	ND	ND	ND	ND
751125	955	20.0	7.0	ND	15.5	ND	0.6	0.02	0.02	90	30	ND	ND	ND	ND
751202	1100	21.0	7.2	ND	23.0	5	ND	0.02	0.05	80	40	ND	ND	ND	ND
751209	1030	20.5	7.1	ND	20.5	5	0.4	0.03	0.03	110	20	ND	ND	ND	ND
751215	1000	21.0	7.1	ND	21.0	ND	0.4	0.06	0.06	80	30	ND	ND	ND	ND
751222	935	20.0	7.2	ND	26.0	ND	1.0	0.01	0.01	70	ND	ND	ND	ND	ND
760101	1104	20.9	7.2	ND	26.0	9	0.3	0.04	0.04	40	ND	ND	ND	ND	ND
760108	1140	19.2	7.1	ND	37.0	ND	ND	0.01	0.04	60	ND	20	ND	ND	ND
760112	125	20.3	7.2	ND	25.5	5	ND	0.02	0.02	40	ND	20	ND	ND	ND
760121	1100	19.7	7.4	ND	28.5	5	ND	0.03	0.03	140	20	30	ND	ND	ND
760128	1220	20.3	7.1	ND	24.5	ND	ND	0.02	0.02	180	20	ND	ND	ND	ND
760204	950	20.0	7.6	ND	21.4	ND	ND	0.02	0.02	60	ND	ND	ND	ND	ND
760211	935	19.9	7.0	ND	24.0	ND	ND	0.02	0.02	120	20	ND	10	ND	ND
760218	1000	19.3	7.0	ND	22.5	ND	0.3	0.02	0.02	30	ND	ND	7	6	ND
760225	1015	19.1	7.0	ND	23.5	ND	ND	0.01	0.01	110	ND	20	4	7	ND
760303	1005	18.8	7.2	ND	24.5	ND	ND	ND	ND	40	ND	10	ND	ND	ND
760310	1020	19.0	7.2	ND	24.5	8	ND	ND	ND	10	11	13	ND	ND	ND
760315	1120	19.1	7.2	ND	21.5	ND	ND	0.03	0.03	85	15	10	ND	ND	ND
760324	945	19.0	7.3	ND	24.5	6	ND	0.02	0.02	41	11	15	ND	ND	ND
760331	1030	18.9	7.2	ND	21.5	11	ND	0.02	0.02	52	ND	15	5	ND	ND
760407	1045	19.0	7.1	ND	23.0	7	ND	0.02	0.02	40	22	20	5	ND	ND
760414	215	19.9	7.0	ND	23.0	11	ND	0.01	0.01	208	18	20	5	ND	ND
760421	915	18.7	7.1	ND	21.5	ND	ND	0.02	0.02	33	13	20	100	ND	ND
760510	915	18.8	7.1	ND	16.5	18	ND	0.01	0.01	93	10	25	8	ND	ND
760526	1005	18.2	7.6	ND	20.5	6	ND	0.03	0.03	77	10	32	10	ND	ND
760609	945	18.8	7.3	ND	19.0	6	ND	0.03	0.05	101	10	ND	ND	ND	ND
760624	1115	18.8	7.0	ND	20.0	5	0.4	ND	ND	88	11	17	ND	ND	ND
760707	1050	19.6	7.4	ND	21.0	ND	ND	0.01	0.01	74	14	16	ND	ND	ND
760722	1105	19.2	7.3	ND	25.5	9	ND	0.02	0.02	55	40	42	ND	ND	ND
760805	1045	20.2	7.2	ND	21.0	6	0.3	0.02	0.02	155	22	24	4	ND	ND
760831	220	20.5	7.1	ND	25.2	ND	ND	0.02	0.02	540	10	10	6	ND	ND
760916	1015	20.0	7.2	ND	27.5	12	0.3	ND	ND	50	22	13	ND	ND	ND
760928	1104	19.0	7.2	ND	22.0	10	0.5	ND	ND	39	18	ND	ND	ND	ND
761019	1055	19.4	7.1	ND	31.0	9	0.3	0.01	0.01	55	13	20	5	ND	ND
761103	955	19.9	7.1	ND	19.0	9	0.3	0.02	0.03	29	17	23	ND	ND	ND
761111	1105	19.6	7.2	ND	22.0	ND	ND	ND	ND	170	15	20	7	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	µg/ml	µg/ml			ng/ml					
Domestic Deep Well - Location No. 13															
751118[a]	1130	20.0	7.0	ND[b]	5.1	10	ND	0.04	0.04	50	30	ND	ND	ND	ND
751125	1015	19.0	7.0	ND	9.8	ND	0.4	0.02	0.05	10	20	ND	ND	ND	ND
751209	1045	19.5	7.0	ND	14.8	5	0.5	0.01	0.01	110	20	ND	ND	ND	ND
751216	1030	17.2	7.0	ND	8.2	9	ND	0.01	0.03	90	40	20	ND	ND	ND
751222	945	19.5	7.2	ND	11.8	6	1.0	0.04	0.04	10	20	ND	ND	ND	ND
760101	1112	12.1	7.1	ND	13.6	103	0.7	0.06	0.06	120	40	20	ND	ND	ND
760108	1215	12.5	7.0	ND	16.2	35	ND	0.02	0.10	2250	ND	ND	ND	ND	ND
760112	130	19.9	8.0	ND	14.4	ND	ND	0.01	0.04	40	ND	40	ND	ND	ND
760121	1115	19.1	7.0	ND	17.2	23	ND	0.03	0.04	150	30	ND	ND	ND	ND
760128	1240	19.4	7.1	ND	16.6	13	ND	0.03	0.03	180	20	ND	ND	ND	ND
760204	1005	20.0	7.1	ND	16.0	22	ND	0.02	0.02	170	20	ND	ND	ND	100
760211	950	19.1	7.0	ND	8.8	6	0.3	0.03	0.03	130	20	ND	8	ND	40
760218	1015	19.3	7.0	ND	13.8	8	0.4	0.03	0.03	20	ND	ND	8	7	ND
760225	1030	17.9	7.0	ND	7.8	9	ND	0.02	0.02	90	ND	ND	7	6	ND
760303	1020	20.7	6.9	ND	8.4	9	ND	0.03	0.03	40	ND	15	ND	ND	ND
760310	1035	18.3	7.4	ND	11.4	36	ND	0.02	0.03	44	19	ND	ND	ND	ND
760315	1135	19.9	7.2	ND	12.2	14	ND	0.04	0.12	62	31	10	ND	ND	ND
760324	145	19.5	7.0	ND	12.0	16	ND	0.02	0.04	250	360	10	ND	ND	ND
760331	200	19.3	6.9	ND	10.2	29	ND	ND	ND	90	58	10	ND	ND	ND
760407	1100	17.3	6.9	ND	7.2	39	ND	0.02	0.02	68	35	20	5	ND	ND
760414	230	20.1	7.0	ND	15.2	14	0.4	0.02	0.02	173	39	20	6	ND	ND
760421	925	18.4	7.0	ND	10.2	23	ND	0.03	0.03	50	49	20	6	ND	ND
760510	1250	19.3	7.0	ND	16.6	23	ND	0.04	0.04	305	18	20	5	ND	70
760526	1020	19.0	7.1	ND	19.0	54	ND	0.03	0.03	75	20	32	8	ND	ND
760609	1020	19.7	7.3	ND	17.5	26	ND	0.03	0.07	175	22	15	5	ND	ND
760624	1145	19.4	7.0	ND	14.0	16	0.3	ND	0.02	104	14	18	ND	ND	ND
760707	1105	22.2	7.5	ND	16.0	89	0.3	0.04	0.05	160	38	16	5	ND	ND
760722	1120	21.6	7.2	ND	20.0	42	ND	0.02	0.02	120	46	33	ND	ND	ND
760805	1115	24.7	7.0	ND	14.5	46	ND	0.02	0.02	240	59	29	4	ND	ND
760831	1015	20.0	7.0	ND	10.0	36	ND	0.02	0.02	125	25	ND	ND	ND	ND
760916	1040	19.5	7.0	ND	12.5	38	0.4	ND	ND	49	16	13	ND	ND	50
760928	1111	18.3	7.2	ND	20.5	8	ND	ND	ND	92	30	10	ND	ND	ND
761019	1110	19.2	7.1	ND	22.0	53	ND	ND	ND	80	140	23	5	ND	ND
761103	1035	19.1	7.0	ND	13.0	16	ND	0.03	0.03	96	22	26	ND	ND	ND
761111	1120	18.7	7.1	ND	20.5	8	ND	ND	ND	238	20	23	7	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Domestic Deep Well - Location No. 14															
751118[a]	1155	19.5	6.9	ND[b]	10.8	24	ND	0.02	0.02	660	30	50	ND	10	ND
751125	1030	19.0	7.0	ND	10.8	13	ND	0.03	0.03	730	30	40	ND	ND	ND
751202	1125	19.5	7.1	ND	10.6	63	0.4	0.02	0.02	1200	20	ND	ND	ND	ND
751209	1100	19.0	7.0	ND	9.6	15	0.4	0.03	0.06	1050	30	ND	ND	ND	ND
751216	1050	18.0	7.3	ND	9.2	19	0.3	0.03	0.03	1360	40	30	ND	ND	ND
751222	957	18.6	7.0	ND	11.4	20	1.3	0.03	0.03	280	ND	ND	ND	ND	ND
760101	1125	18.0	7.0	ND	12.2	31	0.4	0.02	0.02	870	ND	ND	ND	ND	ND
760108	1225	14.0	7.7	ND	24.0	105	ND	0.01	0.03	70	ND	30	ND	ND	ND
760112	140	18.8	7.2	ND	14.8	26	ND	0.02	0.04	270	ND	30	ND	ND	ND
760121	1130	18.4	7.1	ND	14.4	34	ND	0.03	0.04	970	20	20	ND	ND	ND
760128	1255	18.6	7.0	ND	11.6	23	0.4	0.03	0.03	780	30	ND	ND	ND	ND
760204	1015	18.5	7.2	ND	9.6	36	ND	0.02	0.02	890	20	ND	ND	ND	ND
760211	1005	18.2	7.0	ND	11.2	23	ND	0.02	0.02	690	20	20	10	ND	40
760218	1030	19.3	7.2	ND	11.6	20	0.3	0.02	0.03	20	ND	20	10	7	ND
760315	1150	19.1	7.0	ND	8.4	18	ND	0.02	0.02	770	11	20	5	ND	ND
760324	130	18.6	7.0	ND	2.6	16	ND	0.03	0.04	535	11	15	ND	ND	ND
760331	145	18.2	6.9	ND	11.8	40	ND	0.01	0.01	505	15	10	6	ND	ND
760407	1115	19.0	7.0	ND	9.8	19	ND	0.03	0.03	470	27	25	6	ND	ND
760414	245	20.3	6.9	ND	11.0	23	ND	0.02	0.02	465	23	20	6	ND	ND
760421	935	17.6	7.2	ND	11.0	16	0.3	0.03	0.05	2020	13	25	8	ND	ND
760510	1235	21.0	7.2	ND	18.0	60	ND	0.04	0.04	700	21	20	6	ND	ND
760526	1035	20.3	7.4	ND	19.0	69	ND	0.02	0.06	305	20	38	10	ND	ND
760609	1035	19.5	7.5	ND	19.5	13	ND	0.03	0.08	365	23	15	6	ND	ND
760624	140	21.2	7.1	ND	16.5	13	ND	0.01	0.01	325	19	19	5	ND	ND
760707	1125	23.7	7.6	ND	17.0	18	ND	0.01	0.01	370	22	16	ND	ND	ND
760722	1150	20.5	7.2	ND	20.0	19	ND	0.02	0.02	225	46	42	ND	ND	ND
760805	1245	21.0	7.3	ND	16.0	9	ND	0.01	0.04	345	22	15	ND	ND	ND
760831	1055	22.0	7.3	ND	17.5	8	ND	0.01	0.01	353	22	10	ND	ND	ND
760916	1115	20.3	7.2	ND	18.5	12	0.3	ND	ND	210	13	13	ND	ND	50
760928	1140	18.8	7.2	ND	13.0	8	ND	ND	ND	133	20	10	ND	ND	ND
761019	1120	17.8	7.0	ND	18.0	9	ND	0.02	0.02	97	15	23	6	ND	ND
761103	1100	18.9	7.1	ND	13.0	13	ND	0.01	0.01	101	24	23	5	ND	ND
761111	1150	18.3	7.2	ND	14.0	ND	ND	0.02	0.02	280	17	26	8	ND	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 19. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
Domestic Deep Well - Location no. 16															
751118[a]	125	20.5	6.9	ND[b]	5.4	10	2.6	0.06	0.06	60	20	20	ND	10	ND
751125	1150	19.5	7.0	ND	8.8	ND	0.4	0.02	0.02	30	ND	ND	10	ND	ND
751202	125	20.0	7.0	ND	11.8	5	ND	0.02	0.02	50	20	ND	ND	ND	ND
751209	1230	20.0	7.0	ND	12.0	5	0.3	ND	ND	100	40	ND	ND	ND	100
751216	1200	19.7	7.0	ND	11.0	ND	ND	0.02	0.02	70	30	ND	ND	10	ND
751222	1050	19.0	7.0	ND	13.2	ND	0.9	0.02	0.02	60	50	ND	ND	ND	ND
760108	145	18.0	7.0	ND	22.0	10	ND	0.02	0.07	60	50	ND	ND	ND	ND
760112	300	19.9	7.0	ND	15.[illegible]	6	ND	0.01	0.07	20	20	40	ND	ND	ND
760121	110	19.6	7.5	ND	16.4	8	ND	0.04	0.04	50	20	ND	ND	ND	ND
760128	400	19.7	7.0	ND	15.8	ND	ND	0.03	0.03	100	30	ND	ND	ND	ND
760204	1115	19.5	7.2	ND	14.0	6	ND	0.03	0.03	80	30	ND	ND	ND	ND
760211	1120	19.2	7.0	ND	13.4	ND	0.5	0.02	0.02	30	40	30	8	ND	ND
760218	1235	18.5	7.4	ND	13.6	ND	0.3	0.02	0.02	30	20	ND	7	6	ND
760225	1210	18.7	7.0	ND	13.0	ND	0.4	0.03	0.03	110	30	ND	7	6	ND
760303	1050	20.5	7.0	ND	15.8	9	ND	0.01	0.02	60	ND	15	ND	ND	ND
760310	1105	20.5	7.1	ND	16.6	19	ND	0.03	0.03	33	19	10	ND	ND	70
760315	145	19.0	7.1	ND	14.0	6	0.5	ND	ND	220	15	10	ND	ND	ND
760324	1145	19.5	7.0	ND	8.8	9	ND	0.03	0.03	130	15	10	ND	ND	ND
760331	1245	17.2	7.0	ND	15.0	16	ND	0.02	0.02	103	19	10	5	ND	ND
760407	1230	18.9	7.1	ND	14.2	11	ND	0.02	0.02	109	19	20	5	ND	ND
760414	315	20.9	7.0	ND	16.0	14	ND	0.03	0.03	133	23	20	5	ND	ND
760421	1010	19.0	7.3	ND	14.2	ND	ND	0.01	0.01	67	18	20	6	ND	ND
760510	1110	18.9	7.1	ND	17.8	13	ND	0.03	0.03	180	10	20	5	ND	ND
760526	1200	21.7	7.6	ND	17.0	14	ND	0.03	0.05	150	23	32	12	ND	ND
760609	105	19.3	7.2	ND	15.0	9	ND	0.05	0.07	285	10	15	6	ND	ND
760624	250	19.9	7.0	ND	13.0	5	ND	ND	0.03	265	17	18	6	ND	ND
760707	1240	20.1	7.4	ND	17.5	7	ND	0.02	0.02	225	17	16	ND	ND	ND
760722	125	19.6	7.0	ND	21.0	11	ND	0.02	0.02	205	50	42	ND	ND	ND
760805	200	19.5	7.0	ND	14.5	6	ND	0.01	0.02	510	25	15	4	ND	ND
760831	1150	19.4	7.2	ND	17.0	ND	ND	0.02	0.02	252	12	10	ND	ND	ND
760916	1230	19.5	7.1	ND	15.5	12	0.4	ND	ND	190	16	13	ND	ND	ND
760928	1235	20.0	7.1	ND	13.5	6	ND	ND	0.04	63	14	ND	ND	ND	50
761019	1221	18.8	7.0	ND	18.0	6	0.6	0.02	0.04	102	11	23	5	ND	ND
761103	1130	19.0	7.1	ND	10.0	0	ND	0.01	0.01	136	20	23	5	ND	ND
761111	1205	18.6	7.1	ND	12.0	ND	ND	ND	ND	225	15	23	7	ND	ND
DOMESTIC DEEP WELLS All Samples (N = 249)															
Mean		19.4	7.2	<0.3	15.7	11	<0.[illegible]	0.02	0.03	199	21	15	<4	<5	<50
Maximum		26.8	8.0	<0.3	37.0	105	2.[illegible]	0.06	0.12	2250	360	170	120	10	150
Minimum		8.3	6.9	<0.3	2.6	< 5	<0.[illegible]	<0.01	<0.01	< 10	<10	<10	<4	<5	<50
Standard deviation		2.0	0.2	<0.3	5.9	15	0.[illegible]	0.01	0.02	264	28	16	7	2	21

[a] Year, month, day
[b] Not detectable

TABLE 20. CHEMICAL ANALYSIS OF WATER SAMPLES TAKEN FROM TOM GREEN COUNTY DEEP WELLS

Date	Time	Temp.	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
							LOCATION NO. 31								
760329[a]	825	18.4	7.0	ND[b]	7.0	ND	ND	0.05	0.05	105	15	20	ND	5	ND
760520	930	21.0	7.1	ND	4.7	ND	ND	0.04	0.06	77	20	25	ND	ND	ND
760628	825	23.3	7.4	ND	4.9	ND	ND	0.02	0.02	58	12	15	5	5	ND
760714	840	22.7	7.2	ND	3.8	ND	ND	0.02	0.02	118	22	16	ND	ND	ND
760812	725	24.5	7.0	ND	4.2	ND	ND	ND	ND	56	27	10	ND	ND	ND
760921	805	21.5	7.3	ND	6.5	ND	ND	ND	ND	57	16	10	ND	5	ND
761005	810	19.0	7.3	ND	10.6	ND	ND	0.01	0.01	47	ND	14	5	ND	ND
761122	830	16.0	7.2	ND	8.8	ND	ND	ND	ND	140	14	14	7	ND	ND
							LOCATION NO. 32								
760329	900	21.3	7.0	ND	22.5	ND	ND	0.04	0.04	130	15	10	ND	ND	ND
760520	950	21.8	7.1	ND	25.0	ND	ND	0.02	0.02	77	20	25	ND	ND	ND
760628	855	21.5	7.7	ND	26.5	ND	ND	0.03	0.03	58	12	15	5	5	ND
							LOCATION NO. 33								
760329	915	17.2	7.0	ND	35.5	ND	ND	ND	ND	320	11	30	ND	5	ND
760520	1005	20.8	7.0	ND	26.5	9	ND	0.03	0.03	340	13	38	5	ND	100
760628	910	22.0	7.5	ND	28.5	41	0.5	0.01	0.01	225	12	18	5	ND	50
760714	910	24.2	7.2	ND	34.5	39	ND	0.01	0.01	643	11	20	6	5	ND
760812	800	25.8	7.1	ND	35.5	8	ND	ND	0.03	240	ND	20	ND	ND	ND
760921	835	20.8	7.1	ND	45.5	ND	ND	ND	ND	240	ND	10	ND	ND	ND
761005	835	20.5	7.4	ND	80.0	ND	ND	0.01	0.03	283	ND	17	6	ND	ND
761122	900	18.4	7.6	ND	45.0	ND	ND	ND	ND	285	10	17	5	5	ND
							LOCATION NO. 34								
760329	940	19.6	7.0	ND	10.0	ND	ND	0.02	0.03	680	15	15	5	5	ND
760520	255	23.8	7.2	ND	26.5	ND	0.6	0.02	0.03	1600	23	58	10	5	120
760628	920	24.5	7.4	ND	11.5	ND	ND	0.01	0.01	438	15	15	ND	ND	ND
760714	950	24.1	7.1	ND	22.5	ND	ND	ND	ND	783	19	20	6	ND	ND
760812	815	26.0	7.5	ND	12.5	ND	ND	ND	ND	302	12	15	ND	ND	ND
760921	900	23.0	7.2	ND	29.5	8	0.4	ND	ND	1020	28	33	6	9	ND
761005	849	21.9	7.3	ND	38.0	5	ND	0.01	0.02	503	14	23	6	9	ND
761122	930	15.6	7.3	ND	29.5	18	ND	ND	ND	1210	20	30	10	5	ND
							LOCATION NO. 35								
760329	1100	22.0	7.1	ND	2.4	ND	ND	ND	ND	460	15	30	6	5	70
760520	1125	28.8	7.0	ND	2.5	9	ND	0.02	0.02	1190	10	38	5	5	100
760628	945	24.8	7.7	ND	2.4	45	ND	0.01	0.01	850	17	18	10	ND	50
760714	1010	22.6	7.1	ND	1.3	ND	ND	0.01	0.02	413	14	16	5	ND	ND
760812	840	22.5	7.2	ND	2.9	20	ND	0.01	0.05	594	12	20	6	ND	ND
760921	935	22.2	7.2	ND	4.1	ND	ND	ND	ND	515	16	28	5	9	50
761005	1001	21.5	7.3	ND	7.0	ND	ND	0.01	0.03	483	16	23	5	ND	ND
761122	950	19.0	7.4	ND	5.6	ND	ND	ND	ND	790	20	21	7	5	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 20. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
						LOCATION NO. 36									
760329[a]	1125	20.8	7.0	ND[b]	27.0	ND	ND	ND	ND	140	44	15	5	5	70
760520	1140	24.0	7.0	ND	26.5	5	ND	0.02	0.03	75	74	45	5	5	100
760628	1010	26.5	7.7	ND	26.5	ND	ND	0.01	0.01	49	41	22	8	9	50
760714	1030	24.0	7.1	ND	25.5	10	ND	0.02	0.02	168	86	25	7	ND	80
760812	850	28.0	7.0	ND	25.0	8	ND	0.01	0.01	98	30	20	4	ND	ND
760921	955	22.8	7.1	ND	18.5	350	0.7	0.04	0.08	61	26	44	9	9	100
761005	954	17.9	7.4	ND	20.0	33	0.6	ND	0.05	49	22	29	6	5	ND
761122	1005	10.1	7.2	ND	33.0	ND	ND	ND	ND	90	22	23	9	5	ND
						LOCATION NO. 37									
760329	1150	21.5	7.1	ND	1.7	ND	ND	0.05	0.05	460	15	15	ND	ND	ND
760520	1155	25.8	7.0	ND	1.8	ND	ND	0.01	0.02	315	ND	ND	ND	ND	80
760628	1020	27.3	8.0	ND	2.2	ND	ND	0.01	0.01	266	ND	ND	ND	ND	ND
760714	1050	24.0	7.8	ND	1.9	ND	ND	0.01	0.01	618	11	ND	ND	ND	ND
760812	910	27.0	7.6	ND	1.7	ND	ND	ND	ND	300	ND	ND	ND	ND	ND
760921	1015	22.4	7.5	ND	0.3	5	ND	0.01	0.01	750	ND	ND	ND	ND	50
761005	945	20.2	7.8	ND	2.5	8	ND	0.01	0.02	653	ND	10	ND	ND	ND
761122	1025	13.0	7.8	ND	1.7	ND	ND	0.01	0.01	520	ND	17	5	5	ND
						LOCATION NO. 38									
760329	1215	20.8	7.0	ND	7.2	ND	ND	0.02	0.02	720	31	10	7	5	ND
760520	1220	21.8	7.1	ND	6.0	ND	ND	0.02	0.03	820	ND	ND	ND	ND	80
760628	1045	26.8	7.3	ND	10.0	6	ND	0.01	0.09	544	ND	10	5	ND	ND
760714	1115	22.9	7.6	ND	7.8	ND	ND	0.01	0.01	2083	11	ND	ND	ND	ND
760812	925	25.0	7.3	ND	7.8	6	0.4	0.02	0.02	800	ND	10	ND	ND	ND
760921	1040	22.4	7.2	ND	7.6	5	ND	ND	ND	2310	10	ND	ND	5	ND
761005	916	16.2	7.5	ND	13.8	11	ND	0.01	0.01	1870	ND	17	5	ND	ND
761122	1045	9.3	7.3	ND	7.0	ND	ND	ND	0.02	5170	ND	14	7	ND	ND
						LOCATION NO. 39									
760329	125	20.4	6.5	ND	11.5	ND	ND	ND	0.02	290	15	55	ND	ND	130
760520	115	22.0	6.9	ND	7.5	ND	ND	0.01	0.13	410	16	70	10	7	100
760628	1125	27.5	7.3	ND	12.5	ND	ND	ND	0.01	6809	17	40	12	15	100
760714	1115	22.9	7.6	ND	7.8	ND	ND	0.01	0.01	16940	30	56	12	11	105
760812	955	27.0	7.0	ND	13.0	90	ND	0.01	0.02	9202	21	51	10	10	100
760921	1110	21.0	7.1	ND	12.5	240	0.7	ND	ND	19118	22	88	18	15	175
761005	1124	19.9	7.0	ND	18.0	22	0.6	ND	0.01	21175	16	63	13	14	100
761122	1115	8.2	7.1	ND	11.0	119	ND	ND	ND	12100	26	54	16	8	100

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 20. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
							LOCATION NO. 40								
760329[a]	145	20.0	6.7	ND[b]	10.0	ND	ND	ND	ND	175	11	45	11	ND	100
760520	140	21.0	7.0	ND	15.5	9	0.4	ND	ND	100	13	52	7	7	100
760628	1130	21.4	7.0	ND	15.0	ND	ND	ND	0.01	59	25	45	13	12	70
760714	1255	22.8	7.2	ND	13.5	6	ND	0.01	0.01	19	47	383	10	ND	80
760812	1010	25.0	7.2	ND	10.5	6	ND	ND	ND	140	12	42	7	ND	50
							LOCATION NO. 41								
760329	215	21.5	7.0	ND	24.0	6	ND	ND	ND	230	19	25	ND	5	ND
760520	200	21.6	7.0	ND	27.0	11	ND	0.01	0.03	275	29	32	5	5	60
760628	1105	20.8	7.5	ND	29.5	6	ND	0.01	0.01	50	28	22	6	ND	50
760714	120	21.0	7.0	ND	27.5	10	ND	0.01	0.01	213	37	25	6	ND	ND
760812	945	21.5	7.4	ND	24.5	ND	ND	0.03	0.03	99	12	24	4	ND	ND
760921	1050	22.4	7.2	ND	25.5	8	ND	ND	ND	145	16	17	5	8	50
761005	1135	20.9	7.3	ND	37.5	ND	ND	0.01	0.01	273	ND	26	8	ND	ND
761122	1100	10.8	7.2	ND	24.0	11	ND	ND	ND	370	10	23	9	5	250
							LOCATION NO. 42								
760329	240	20.8	7.0	ND	18.0	5	ND	ND	ND	210	11	15	ND	ND	ND
760520	215	20.7	7.1	ND	24.0	21	ND	0.02	0.02	121	13	15	7	5	ND
760628	1140	21.0	7.2	ND	24.0	6	ND	0.01	0.01	88	12	15	6	9	50
760714	135	20.5	7.2	ND	26.0	35	ND	0.01	0.01	283	ND	16	5	ND	ND
760812	1020	21.0	7.2	ND	27.5	6	ND	0.01	0.01	107	12	20	4	ND	ND
760921	1130	23.0	7.6	ND	31.5	23	ND	ND	ND	412	10	17	ND	8	50
761005	1100	21.9	7.4	ND	42.0	ND	ND	0.01	0.01	383	ND	20	8	ND	ND
761122	1145	12.8	7.4	ND	27.0	ND	ND	ND	ND	610	NS	17	10	5	ND
							LOCATION NO. 43								
760329	305	22.7	7.4	ND	2.1	10	ND	0.02	0.03	390	84	10	ND	ND	ND
760520	235	22.3	7.0	ND	2.3	5	ND	0.01	0.11	515	135	25	ND	ND	ND
							LOCATION NO. 44								
760329	320	20.5	7.0	ND	46.5	13	ND	ND	ND	255	19	25	ND	ND	ND
760520	255	21.0	7.2	ND	25.0	44	1.1	0.01	0.01	160	13	88	10	5	ND

[a] Year, month, day
[b] Not detectable

(continued)

TABLE 20. (continued)

Date	Time	Temp	pH	NH_4^+-N	NO_3^--N	NO_2^--N	Kjeldahl N	Dissolved Ortho-P	Total P	Zn	Cu	Ni	Cd	Cr	Pb
		°C		µg/ml	µg/ml	ng/ml	µg/ml			ng/ml					
							LOCATION NO. 45								
760329[a]	335	19.8	7.1	ND[b]	39.0	ND	ND	0.02	0.02	650	11	15	ND	ND	ND
760520	325	19.5	7.1	ND	49.5	103	0.4	0.01	0.03	4950	ND	38	8	ND	60
760628	1225	21.5	7.6	ND	54.0	13	ND	0.01	0.01	1848	15	10	5	ND	ND
760714	235	23.0	7.3	ND	61.0	625	ND	0.01	0.11	1753	14	10	ND	ND	ND
760812	1005	23.0	7.3	ND	47.0	75	ND	0.01	0.05	570	ND	ND	ND	ND	ND
760921	100	23.6	7.4	ND	57.0	38	ND	ND	ND	2101	ND	10	ND	8	ND
761005	1020	21.2	7.5	ND	67.0	23	ND	0.01	0.03	1595	ND	14	6	ND	ND
761122	1245	11.6	7.3	ND	45.0	23	0.5	ND	ND	2772	ND	11	7	5	ND
							LOCATION NO. 46								
760714	155	23.7	7.1	ND	1.9	10	ND	0.01	0.02	5273	ND	10	5	ND	ND
760812	1035	31.0	7.5	ND	1.8	ND	ND	ND	ND	4125	ND	ND	4	ND	ND
760921	1145	22.5	7.5	ND	2.6	ND	ND	0.01	0.01	4400	10	ND	ND	ND	ND
761005	1045	20.5	7.5	ND	3.2	ND	ND	0.01	0.01	4735	ND	10	5	ND	ND
761122	1205	9.0	7.3	ND	2.3	ND	ND	ND	0.02	5555	ND	ND	5	5	ND
							LOCATION NO. 47								
760714	215	22.7	7.2	ND	36.5	10	ND	0.01	0.09	7583	ND	10	5	ND	ND
760812	1050	23.0	7.3	ND	45.0	6	ND	ND	ND	330	ND	10	ND	ND	ND
760921	1230	23.0	7.3	ND	38.0	5	ND	ND	ND	630	19	17	ND	6	ND
761005	1037	17.3	7.4	ND	57.0	5	ND	0.01	0.01	483	ND	14	6	ND	ND
761122	1230	16.4	7.1	ND	36.0	ND	ND	ND	ND	1000	ND	ND	ND	5	ND
							LOCATION NO. 48								
760812	745	23.2	7.4	ND	60.0	6	ND	ND	ND	350	15	10	ND	ND	ND
760921	820	18.2	7.2	ND	48.5	13	ND	ND	ND	1540	34	10	ND	5	ND
761005	830	20.2	7.4	ND	64.0	ND	ND	0.01	0.01	203	10	14	5	ND	ND
761122	845	9.3	7.2	ND	49.0	14	ND	ND	0.02	700	12	14	5	ND	ND
							All Samples (N=114)								
Mean		7.3	< 0.3	22.0	20	< 0.30	< 0.30	< 0.010	0.018	1572	16	25	5	< 5	< 50
Minimum		6.5	< 0.3	0.3	< 5	< 0.30	< 0.010	< 0.010	< 0.010	19	<10	< 10	< 4	< 5	< 50
Maximum		8.0	< 0.3	84.0	625	1.10	0.050	0.130	21175	135	383	18	15	250	
Standard deviation		0.2	0	18.4	72	0.19	0.011	0.024	3497	19	38	4	4	46	

[a] Year, month, day
[b] Not detectable

TABLE 21. AVERAGE COD, BOD, TFR, AND TNFR ANALYSIS OF WATER SAMPLES FROM THE CONCHO RIVER, SEWAGE FARM LAGOONS, SEEPS AND WELLS AND TOM GREEN COUNTY WELLS

Sample Number	Location	BOD	COD	Total Filterable Residue	Total Nonfilterable Residue
		ug/ml			
	SEWAGE FARM				
1	Concho River - upstream	3.8	65	965	30
2	Concho River - downstream	3.1	58	975	25
3	Effluent Lagoon 1	148.0	400	1298	968
4	Effluent Lagoon 4	89.0	280	1382	1060
5	Seepage Creek no. 1	9.2	80	1630	70
6	Seepage Creek no. 2	0.6	58	1438	33
7	Seepage Creek no. 3	0.6	62	2200	30
8	Shallow Well	0.7	100	1648	40
9	Domestic Well	1.6	64	2245	73
10	Domestic Well	1.3	38	1660	57
12	Domestic Well	0.1	38	1691	68
13	Domestic Well	0.6	48	1625	63
14	Domestic Well	0.9	52	1763	72
16	Domestic Well	0.5	38	1673	93
18	Shallow Well	1.0	102	1803	92
19	Shallow Well	1.3	62	1222	83
20	Shallow Well	0.7	74	1933	110
21	Shallow Well	1.6	54	2110	102
22	Sewage Treatment Plant	146.0	502	1528	605
	TOM GREEN COUNTY WELLS				
31	Domestic Well	1.6	46	1528	78
33	Domestic Well	1.2	6	1240	105
34	Domestic Well	1.3	15	3200	100
35	Domestic Well	0.5	11	2770	115
36	Domestic Well	0.8	10	2445	130
37	Domestic Well	1.8	<10	485	100
38	Domestic Well	1.5	<10	808	152
39	Domestic Well	0.1	34	5088	43
41	Domestic Well	2.3	28	1603	<23
42	Domestic Well	0.1	11	1485	20
45	Domestic Well	2.1	<10	1025	<21
46	Domestic Well	1.1	<10	470	20
47	Domestic Well	0.6	42	1198	21
48	Domestic Well	1.5	25	1035	30

NO_2^- nitrogen higher than 10 µg/ml may result in a high potential risk of methemoglobinemia to bottle-fed infants. Waters with a NO_2^--N concentration over 1 µg/ml should not be used for infant feeding. A limit of 0.02 µg/ml of nonionized NH_3 has been recommended as the water quality criteria for freshwater aquatic life (EPA 1976). A chemical equilibrium exists between nonionized NH_3 and NH_4^+ ion. At 20°C and a pH of 8.0 only 3.8 percent of the nitrogen is present as nonionized NH_3 in aqueous solution. The other 96.2 percent is present as NH_4^+ ions. There is no water quality criteria for NO_3^- or NH_3 for livestock water supplies. Campbell and others (NTAC, 1968) have reported methemoglobinemia in cattle receiving water containing 2,790 µg/ml of NO_3^--N.

In ruminant animals, NO_3^- may be reduced to NO_2^- by microflora in the rumen. Nitrite may then exert toxic effects on the animal. High concentrations of NO_3^- and/or NH_4^+ in waters may also stimulate growth of undesirable plants and decrease recreation uses. The toxicity of ammonia is dependant upon pH, temperature, the concentration of total ammonia ($NH_3 + NH_4^+$), and ionic strength. The concentration of NH_3 increases with increasing temperature and decreases with increasing ionic strength. Lykins and Smith (1976) reported that Missouri has the most stringent standard of NH_3 (0.1 µg/ml) for streams. Nevada and California have the lowest NO_3^--N value (1.0 µg/ml), and Delaware has the lowest total nitrogen value (3.0 µg/ml).

Nitrogen entered the sewage treatment plant primarily as NH_4^+-N (Table 11). The 12 month mean was 16.3 µg NH_4^+-N/ml but fluctuated between 12.0 and 29.2 µg/ml over the year. In addition, an average of 5.9 µg/ml organic N entered the treatment plant (difference between Kjeldahl-N and NH_4^+-N). A trace of NO_2^--N and small but variable quantities of NO_3^--N were present in the incoming effluent.

Ammonium nitrogen was the predominant form in the sewage effluent lagoons (Tables 12 and 13) with mean values of 28.2 and 21.1 µg NH_4^+-N/ml found in effluent lagoons 1 and 4, respectively. Total Kjeldahl-N also tended to increase in concentration in the lagoons while NO_2^--N and NO_3^--N concentration remained fairly constant.

Once sewage effluent water was applied to the soils, oxidation of NH_4^+-N occurred, and the nitrogen species found in seepage creeks was NO_3^--N (Tables 14, 15, and 16). The exception was seepage creek no. 1 where significant quantities of NH_4^+-N and Kjeldahl-N were measured. Seepage creek no. 1 originates within the boundary of the farm and flows through it. Cattle drink and excrete into the stream. On several occasions effluent was detected flowing directly from the irrigation lines into seepage creek no. 1. These two factors probably largely account for the levels of NH_4^+-N, Kjeldahl-N and NO_2^--N measured in the seepage creek no. 1 compared to seepage creeks 2 and 3 (Tables 15 and 16). The latter two seeps were discharging from the bank of the Concho River. They were fenced to exclude cattle from drinking from them. There was no possibility of surface flow into these seeps, so all of the water had to pass through the soil profile. Consequently, NH_4^+-N, NO_2^--N and Kjeldahl-N were detected sporadically and in

small quantities. Except for the high NO_3^--N concentration (16.3 and 21.0 µg/ml) in seeps 2 and 3, the water was of good quality.

The mean NO_3^--N value of water from all three seepage creeks is higher than 10 µg/ml. The lower the water flow rate of these three seepage creeks, the higher the nitrate value found in the waters (Tables 14, 15 and 16). The average value of 183 ng NO_2^--N/ml in seepage creek no. 1 was much higher than values in seepage creeks no. 2 and 3.

There was a significant increase in the nitrate concentration of Concho River waters below compared to that above the sewage farm (Tables 17 and 18). The discharge of treated sewage effluent from the sewage farm into the Concho River (via seepage and some surface runoff) increased the nitrate concentration of river waters from a mean value of 1.6 ± 1.0 to 5.7 ± 2.0 µg/ml NO_3^--N. Because the NO_3-N value of downstream waters is less than the standard of 10 µg/ml (except on January 8, 1976, a value of 14.0 µg/ml was observed), a minimal environmental impact is expected. No significant increase in Kjeldahl-N, NH_4^+-N, and NO_2^--N concentrations was observed in the Concho River below the sewage farm.

The nitrate values of shallow ground wells and domestic deep wells in the sewage farm are 5.8 ± 5.2 and 15.7 ± 5.9 µg NO_3-N/ml, respectively (Table 19). Both the NH_4^+-N and Kjeldahl-N concentrations are below the detection limit. Waters of high concentration of NO_3^--N are not suitable for drinking, but they do make a good source of plant nutrients. Most deep well water in Tom Green County has a high concentration of NO_3^--N. At sampling locations no. 33, 45, 47, and 48, the concentration of NO_3^--N is higher than 50 µg/ml (Table 20). Comparison of the NO_3^--N concentration of deep wells in the sewage farm and that of Tom Green county wells indicated that application of sewage wastewater to the farm did not increase the NO_3^--N concentration. The average NO_3^--N concentration of deep well water from the sewage farm was 15.7 (Table 19) while that of the deep wells located in Tom Green county was 22.0 (Table 20).

In a study to determine the source of NO_3 in ground water using N^{15} isotope, Kreitler (1975) found that the major source of nitrate in ground water in the San Angelo area is from natural soil nitrate, which was derived from the mineralization of organic nitrogen in the soil. He indicates that the Permian carbonate aquifers and the tertiary gravel aquifer have no downdip portion so the entire aquifer has been polluted. He concluded that the oxidation of part of the humus of semiarid grassland soils and the subsequent leaching of the NO_3^- to the saturated zone by extensive terracing in the 1950's resulted in the high NO_3^- concentration in the ground waters in this area.

Phosphorus

Phosphorus is one of the major essential elements for plant growth. In general, evidence indicates that high phosphorus concentrations are associated with accelerated eutrophication of waters, when other growth-promoting factors are present. Phosphorus is not the sole cause of eutrophication but there is substantiating evidence that frequently it is

the key element required by freshwater plants. Because it is present in the least amount relative to need, phosphorus is one of the most easily controlled elements required for plant growth by man's activity. Under normal soil and water conditions plants take up phosphorus in the $H_2PO_4^-$ forms. It is well-known that phosphorus concentrations critical to noxious plant growth vary, and nuisance growths may result from a particular phosphorus concentration in one geographical area but not in another.

A level of 100 µg/l total P has been suggested by MacKenthum (1973) as the desired water quality criteria for the prevention of plant nuisance in streams or other flowing waters not discharging directly into lakes or impoundments. At the time of the spring turnover total phosphate concentrations in excess of 25 µg P/l may occasionally stimulate excessive or nuisance growths of algae and other aquatic plants and interfere with water treatment (EPA 1976). Lykins and Smith (1976) reported that Hawaii has the most stringent total phosphate phosphorus standard (20 µg P/l) for streams. At present no national criterion is presented for phosphate phosphorus for the control of eutrophication (EPA 1976).

The sewage farm is receiving about 67,900 kg total P/year from the city of San Angelo if an average value of 0.219 m^3/sec of raw sewage is assumed. The phosphorus is present as about 50 percent dissolved orthophosphate and 50 percent organic phosphorus (Table 11). The average orthophosphate concentration in 1976 was 5.08 µg/ml and the average total phosphorus concentration was 9.83. Considerable fluctuation in phosphate concentration was apparent during the year; however, the ratio of ortho- to total phosphorus remained about the same. As the sewage effluent passed through the lagoons the ortho- and total phosphorus concentration tended to increase somewhat. The average total phosphate concentration of effluent water at the sewage treatment plant, lagoon no. 1 and lagoon no. 4 were 9.83 ± 3.71, 24.94 ± 8.02, and 18.45 ± 6.92 µg P/ml, respectively (Tables 11, 12 and 13). The dissolved orthophosphate concentrations of the effluent at these three locations were 5.08 ± 2.05, 11.35 ± 4.36, and 7.58 ± 4.16 µg P/ml.

Both the dissolved orthophosphate and total phosphorus of water sampled at seepage creek no. 1 exceeded 100 µg P/l (Table 14). From the middle of February to early July, the total phosphorus concentration of seepage creek no. 1 water often exceeded 1,000 µg P/l. In the spring of the year, total phosphorus concentrations of seepage creeks no. 2 and 3 were higher than 25 µg P/l (Tables 15 and 16). All three seepage creeks had high total phosphorus concentration in the spring time and produced thick, dense algae growth. Algal growth interfered with water flow through weirs installed at the three seepage creeks and required frequent cleaning of the weirs to obtain accurate data.

Comparison of the dissolved orthophosphate and total phosphate between domestical deep wells at the sewage farm and Tom Green County wells indicated that no significant difference in phosphorus concentrations is found (Table 19 and 20). Apparently the application of sewage effluent to the soil does not increase the dissolved orthophosphate or total phosphorus concentrations in underground water. Because no downdip portion existed in the carbonate and gravel aquifers, water moves laterally rather than

vertically in the soil profile. This water movement apparently results in higher phosphorus concentrations in surface flow waters (Concho River and seepage creeks), but not in deep well groundwater. Control measures to prevent the development of excessive vegetative growth within the water ways are necessary for the long-term operation of the sewage farm.

A slight increase was found in the total phosphate in the Concho River waters below the San Angelo sewage farm (Tables 17 and 18). Total phosphorus concentration above the sewage farm was 0.060 µg P/ml. The concentration below the farm was 0.078 µg P/ml. Dissolved orthophosphate increased from 0.017 to 0.019 µg P/ml. Waters flowing from the seepage creeks are probably representative of those flowing from the sewage farm in terms of P concentration. Total phosphorus ranged from 0.03 µg P/ml in seepage creek 3 to 0.79 µg P/ml in seepage creek 1. Dissolved orthophosphate ranged from 0.02 to 0.36 µg P/ml for the same two sites.

Heavy Metals

Excessive concentrations of heavy metals in water may constitute a very serious form of pollution. Heavy metals form relatively stable compounds and are not readily removed by natural processes. A characteristic feature of heavy metal pollution is its persistence in time as well as in space for years after the pollution practices have ceased (NTAC 1968). Living organisms can take up heavy metals from a solution against a concentration gradient and concentrate them above that level normally found in the medium. The order of affinity of cations for plankton generally is Zn>Pb>Cu>Mn>Ni>Cd, and for algae is Pb>Mn>Zn>Cu,Cd>Co>Ni. It is clear that the heavier metals tend to be more readily taken up than the lighter ones, which have a higher degree of hydration. The uptake of heavy metals by living organisms is clearly linked with metabolic activities within the cell. Many environmental factors (such as temperature, oxygen, light) can affect the active uptake process of heavy metals by living organisms.

Heavy metals cause toxic action on the growth and metabolism of an organism even at very low concentration. Many mechanisms of toxic action have been observed: such as the poisoning of enzyme systems, formation of antimetabolites catalyzing the decomposition of essential metabolites, alteration of cell membrane permeability, and replacing important elements in the cell which affect their ability to function. Living organisms exhibit rather marked differences in tolerance to levels of heavy metals in its environment. One of the potential hazards in applying sewage effluent to land is the contamination of groundwater and receiving streams by heavy metals, and the subsequent uptake of heavy metals by aquatic organisms.

The data presented in Table 22 show the water quality criteria for heavy metals for domestic water supply and irrigation use. The values of the National Academy of Science (NAC 1973) refer to recommended maximum concentrations of trace elements in irrigation waters used for sensitive crops on coarse-textured soils with low capacities to retain heavy metals. Lykins and Smith (1976) listed states having most stringent water quality criteria of streams and the concentration of each heavy metal.

Table 22. RECOMMENDED SURFACE AND IRRIGATION WATER QUALITY CRITERIA FOR HEAVY METALS

Elements	Stream (Lykins and Smith) 1976	Domestic Water Supplies (EPA 1976)	Irrigation Water (NTAC 1968)	Irrigation Water (NAS 1973)
	µg/ml			
Cd	0.005 (Ohio)	0.01	0.005	0.01
Cr	0.010 (Ohio)	0.05	5.000	0.10
Cu	0.010 (Minn.)	1.00	0.200	0.20
Ni	1.000 (Ill.)	-	0.500	0.20
Pb	0.040 (Ohio)	0.05	5.000	5.00
Zn	-	5.00	5.000	2.00

Data in Tables 11, 12, and 13 show the heavy metals concentration of incoming sewage effluent at the sewage treatment plant lagoon no. 1 and lagoon no. 4, respectively. The heavy metals concentration of lagoon no. 4 waters, which is irrigated directly to the land, is less than that suggested by the National Technical Advisory Committee (1968) and by the National Academy of Science (1973) for irrigation water (Table 13). The chromium concentration of water decreases from 0.272 ± 0.169 µg/ml at the sewage treatment plant to 0.064 ± 0.021 µg/ml at lagoon no. 4; whereas no significant change was observed in the Cd, Cu, Ni, Pb, and Zn concentrations. The heavy metal concentration of three seepage creeks, the shallow ground wells, and the deep wells for domestic use located within the sewage farm are below the water quality criteria for either domestic water supply or irrigation use (Tables 14, 15, 16 and 19). Most Tom Green County deep well waters have low concentrations of heavy metals for drinking and irrigation purposes (Table 20). Waters sampled at Tom Green County well locations no. 38, 39, 45, 46, and 47 have high zinc concentrations which exceeded the water quality standard for either domestical drinking or irrigation. The zinc concentration of water at sampling site no. 39 increased from 0.29 µg Zn/ml in March to 21.18 µg Zn/ml in October, then dropped to 12.10 µg Zn/ml in November in 1976. It is not clear what causes this high zinc concentration in these waters. Corrosion and contamination of the water by galvanized well pipe is probably the main factor.

No significant difference in Cu, Ni, Cd, Cr, and Pb concentrations in Concho River waters above and below the sewage farm was found (Tables 17 and 18). The average zinc concentration (0.123 ± 0.101 µg/ml) of Concho River water below the sewage farm is higher than that (0.050 ± 0.065 µg/ml) above the sewage farm. The concentrations of heavy metals in the Concho River above and below the sewage farm do not exceed the water quality criteria recommended by the U. S. Environmental Protection Agency (1976) for domestic water supplies. It is clear that the discharge of sewage farm water into the Concho River does not change the water quality of the Concho River with respect to the heavy metals.

BOD and COD

The biochemical oxygen demand (BOD) indicates the relative oxygen requirements of wastewaters, effluents, and polluted waters. It also can be used in evaluating the efficiency (BOD removal) of wastewater treatment systems. The measurement of chemical oxygen demand (COD) provides the oxygen equivalent of that portion of the organic matter in water that is susceptible to oxidation by potassium dichromate. With wastewater containing toxic substances, the COD test may be the only measurement for evaluating the organic load. The BOD and COD values of water at the sewage farm and Tom Green County are listed in Table 21.

The BOD values of incoming sewage wastewater at the sewage treatment plant and effluent lagoon no. 1 are almost the same, 146 and 148 µg/ml, respectively. It drops to 89 µg/ml at effluent lagoon no. 4. The COD value of incoming sewage wastewater is 502 µg/ml. It decreases to 400 and 280 µg/ml at the effluent lagoon no. 1 and 4, respectively. There was essentially no difference between the BOD and COD values of Concho River waters above and below the sewage farm. Therefore, it can be inferred that sewage farm operation has no effect on the BOD and COD values of the Concho River on the dates measured. Considerable reduction in BOD and COD values are apparent between the applied wastewater and the three seepage creek waters. The BOD values of well waters in the sewage farm are similar to those of well waters in Tom Green County. However, well waters in the sewage farm generally had higher values of COD than domestic wells in Tom Green County. Infiltration of applied sewage wastewater into and through the sewage farm soils decrease the BOD and COD values of the wastewater. The soils act as a living filter. In the United States, Nevada has the most stringent BOD criteria level of 1.0 µg/ml for streams (Lykins and Smith 1976). The highest BOD values for deep well waters in this study were 2.1 and 2.3 µg/ml and came from domestic wells located in Tom Green County.

Total Filterable Residue (TFR) and Total Nonfilterable Residue (TNFR)

Waters yielding a high value of residue are generally inferior with respect to palatability, or they may induce an unfavorable physiological reaction in the transient consumer. A limit of 500 µg/ml total filterable residue (TFR) is the permissible criteria, and a limit of less than 200 µg/ml is the desirable level for public drinking water (NTAC 1968). The value of 500 µg/ml TFR is also the recommended level for farmstead use. The state of Illinois has the most stringent total nonfilterable residue (TNFR) level of 5.0 µg/ml; whereas Nevada has the most stringest TFR level of 60 µg/ml (Lykins and Smith 1976). High TNFR values are objectionable because of physiological effects, abnormal taste, or economic effect (corrosion damage in water systems by high concentrations of sulfates and chlorides).

The data presented in Table 21 show TFR and TNFR values of waters from the sewage farm and Tom Green County wells. All waters in the sewage farm and most well waters in Tom Green County have values of TFR greater than 1000 µg/ml. The Concho River waters above and below the

sewage farm have values of 965 and 975 µg/ml, respectively. The deep well located near the treatment plant had the highest value (2245 µg/ml) of TFR in the sewage farm while water sampling site no. 39, located in the city of San Angelo, has the highest value (5088 µg/ml) of TFR in the Tom Green County wells sampled. Comparison of TFR and TNFR values between sewage farm well waters and those from Tom Green County wells indicates that application of sewage wastewater to the soil does not increase the TFR and TNFR values in ground waters in the sewage farm. The high values of TFR in Tom Green County are probably the result of dissolution of salts from underground rocks which are sedimentary origin. The principal ions in the well waters are calcium, bicarbonate, and sulfate, and, in general, the water is excessively hard (Willis, 1954).

There was no apparent difference in TFR and TNFR in Concho River waters sampled upstream or downstream from the sewage farm (Table 21).

Statistical Relationships between Water Parameters

Correlation coefficients between the air and soil temperatures and nutrient concentrations of three seepage creeks are calculated and listed in Table 23. At seepage creeks no. 1 and 2 the zinc concentration is linearly correlated with the air and soil temperatures. The location of the temperature measuring equipment was at the fenced bermudagrass area, adjacent to seepage creek no. 1. No linear correlation is observed between the zinc concentration of seepage creek no. 3 and the measured air and soil temperatures. Waters sampled at seepage creek no. 3 are located in a dense mesquite tree area along the Concho River bank. The temperature of the water at seepage creek no. 3 was usually cooler than that of seepage creeks no. 1 and 2 at the same time of the day. The air and soil temperatures measured at the fenced bermudagrass area are not representative of the air and soil temperature of seepage creek no. 3. A highly significant linear correlation existed between the NO_2^--N concentration of seepage creek no. 3 and the soil temperature at 10 and 40 cm depth.

Linear correlation coefficients between the nutrient concentrations and the temperature of water at the sampling location at the sewage farm were calculated. Furthermore, linear correlation coefficients between nutrient species were also calculated. Only those linear correlation coefficients with an absolute value greater than 0.600 are listed in Table 24. Highly significant linear correlation coefficients between total phosphorus and dissolved orthophosphorus are found at the three seepage creeks and most of the shallow and deep wells at the sewage farm. Water temperature and nitrate concentration of Concho River waters were negatively correlated. Water temperature and dissolved orthophosphate concentration of incoming sewage effluent at the sewage treatment plant, lagoon no. 1, and lagoon no. 4 are also negatively correlated. At the sewage treatment plant the water temperature is negatively correlated with the total phosphorus, total Kjeldahl nitrogen, NH_4^+-N, and dissolved orthophosphorus concentrations. Highly significant positive linear correlation coefficients between total phosphorus, dissolved orthophosphorus, NH_4^+-N and total Kjeldahl nitrogen are found in water samples taken at the sewage treatment

TABLE 23. CORRELATION COEFFICIENTS AND SIGNIFICANT PROBABILITY LEVEL OF DAILY AIR AND SOIL TEMPERATURES VS. NUTRIENT CONCENTRATIONS OF THREE SEEPAGE CREEK WATERS

Temperature	NH_4^+-N	NO_3^--N	NO_2^--N	Kjl-N	Ortho-P	Total-P	Zn	Cu	Ni
	----µg/ml ----		ng/ml	----------	----------	µg/ml	----------	----------	----------
				Seepage creek no. 1					
Air	-0.002	-0.251	0.188	0.081	0.199	0.287	0.540	-0.251	0.210
	0.992	0.188	0.328	0.685	0.300	0.132	0.003	0.189	0.275
Soil at 10 cm	-0.008	0.086	0.225	0.045	0.135	0.191	0.577	-0.037	0.164
	0.967	0.656	0.241	0.820	0.485	0.322	0.001	0.848	0.397
Soil at 40 cm	-0.050	0.151	0.194	0.012	0.120	0.140	0.583	0.057	0.141
	0.798	0.434	0.314	0.952	0.534	0.468	0.001	0.770	0.467
				Seepage creek no. 2					
Air	0.000	-0.227	0.223	0.170	-0.357	-0.404	0.667	0.031	0.150
	1.000	0.236	0.245	0.378	0.058	0.030	0.000	0.874	0.436
Soil at 10 cm	0.000	-0.100	0.378	0.269	-0.250	-0.315	0.675	0.125	0.171
	1.000	0.605	0.043	0.158	0.191	0.096	0.000	0.520	0.376
Soil at 40 cm	0.000	-0.011	0.385	0.302	-0.235	-0.315	0.693	0.181	0.176
	1.000	0.095	0.039	0.111	0.219	0.096	0.000	0.348	0.361

(continued)

TABLE 23. (continued)

Temperature	NH_4^+-N	NO_3^--N	NO_2^--N	Kjl-N	Ortho-P	Total-P	Zn	Cu	Ni
	--- µg/ml ----		ng/ml	---------- µg/ml ----------					
				Seepage creek no. 3					
Air	0.000	-0.227	0.223	0.170	-0.357	-0.404	0.667	0.031	0.150
	1.000	0.236	0.245	0.378	0.058	0.030	0.000	0.874	0.436
Soil at 10 cm	0.000	-0.100	0.378	0.269	-0.250	-0.315	0.675	0.125	0.171
	1.000	0.605	0.043	0.158	0.191	0.096	0.000	0.520	0.376
Soil at 40 cm	0.000	-0.011	0.385	0.302	-0.235	-0.315	0.693	0.181	0.176
	1.000	0.095	0.039	0.111	0.219	0.096	0.000	0.348	0.361

TABLE 24. CORRELATION COEFFICIENTS OF TEMPERATURE AND NUTRIENT CONCENTRATIONS VS. NUTRIENT CONCENTRATIONS OF WATERS IN THE SEWAGE FARM [a]

Sampling Location Number	Correlation Coefficient [b]		Sampling Location Number	Correlation Coefficient [b]	
1	NO_3^--N vs. Temp	-0.800	12	Total-P vs. Ortho-P	0.857
2	Zn vs. Temp	0.754	13	Total-P vs. Ortho-P	0.607
	NO_2^--N vs. Temp	0.624			
	NO_3^--N vs. Temp	-0.601	14	Total-P vs. Ortho-P	0.661
3	NH_4^+-N vs. Ortho-P	0.845	17	Kjl-N vs. NH_4^+-N	0.933
	Temp vs. Ortho-P	-0.718		NO_2^--N vs. Temp	0.683
	NO_3^--N vs. Ortho-P	-0.616		Total-P vs. Ortho-P	0.663
4	Ortho-P vs. NH_4^+-N	0.875	18	Total-P vs. Ortho-P	0.797
	NH_4^+-N vs. Temp	-0.777			
	NO_3^--N vs. NO_2^--N	0.743	19	Total-P vs. Ortho-P	0.972
	Ortho-P vs. Temp	-0.645			
			20	Total-P vs. Ortho-P	0.671
5	NH_4^+-N vs. Kjl-N	0.896			
	Total-P vs. Kjl-N	0.800	22	Total-P vs. Ortho-P	0.924
	Ortho-P vs. Kjl-N	0.796		Ortho-P vs. NH_4^+-N	0.917
	Total-P vs. Ortho-P	0.778		Total-P vs. NH_4^+-N	0.898
	Total-P vs. NH_4^+-N	0.730		Kjl-N vs. NH_4^+-N	0.896
	Temp vs. Zn	0.683		Total-P vs. Kjl-N	0.882
	Ortho-P vs. NH_4^+-N	0.657		Ortho-P vs. Kjl-N	0.866
				Total-P vs. Temp	-0.772
6	Total-P vs. Ortho-P	0.852		Kjl-N vs. Temp	-0.735
				NH_4^+-N vs. Temp	-0.677
7	Total-P vs. Ortho-P	0.774		Ortho-P vs. Temp	-0.644
9	Total-P vs. Ortho-P	0.755			
10	Total-P vs. Ortho-P	0.784			

[a] Correlation coefficients of NH_4^+-N, NO_3^--N, NO_2^--N, Kjl-N, Total-P, Ortho-P Zn, Cu, and Ni versus NO_3^--N, NO_2^--N, Kjl-N, Ortho-P, Total-P, and temperature were calculated for all water sampling locations at the sewage farm. Any coefficient not listed in this table has an absolute value of less than 0.600.

[b] Significant at 1% level

plant and seepage creek no. 1. It is apparent that water temperature influences the concentration of certain nutrients in waters.

PLANT ANALYSIS AND FIELD PLOT EXPERIMENT

One of the major concerns of land disposal of sewage wastes is the cycling of chemical elements in sewage treated soils by the soil-plant system. Sixteen elements have been shown to be essential for plant growth. Four other elements are essential for some plants. Some elements may have little or no effect on plant growth, whereas others may be toxic. Many factors affect the toxicity of an element to a plant including plant species and variety, plant growth stage, soil solution concentration, soil availability and competition, and balance of other elements. Generally, the concentration of a chemical element in plant tissue increases as the concentration and availability of that element in the soil increases if other growth factors are the same. Plant species, even varieties within species, exhibit natural variability and vary markedly in their tolerance to concentrations of specific elements. Balance and competition of other elements are also important in determining plant requirements and toxicity for a particular element. Whenever the concentration of a given element in a plant or the amount of that element supplied by the soil exceeds that needed for sufficient and optimum growth, accumulation or toxicity of that element may occur. The accumulation of toxic elements will in turn determine the long-term loading limits of sewage waste disposal on a land. One of the objectives of this study is to examine the effect of long-term sewage wastewater irrigation on plant growth and crop quality.

The data in Table . show the chemical composition and yield of four forage crops grown at t sewage farm. Each set of data comes from a sample taken from a dif nt part of the field. Coastal bermudagrass was harvested on two differ dates. The nitrogen concentration of individual plant tissues ranged fr .80 percent for Coastal bermudagrass on the first cutting to 1.62 percent the second cutting. This corresponds to 17.50 and 10.13 percent crude protein in plants, respectively. The phosphorus concentrations of plant tissue range from an average of 0.199 percent for the first cutting of Coastal bermudagrass to an average of 0.343 percent for forage sorghum. The yield of the second harvest of Coastal bermudagrass was the highest (6000 Kg/ha), whereas the yield of NK37 bermudagrass was the lowest (2146 Kg/ha). Generally, the nutrient concentration in the first cutting of Coastal bermudagrass is higher than that of the second cutting.

Both zinc and copper are required for normal plant growth. The concentration of copper in plant tissues varies from 3.8 µg/g for the second cutting of the Coastal bermudagrass to 9.1 µg/g for forage sorghum. Allaway (1968) indicated that the normal range of copper in plants is 4-15 µg/g and the toxicity level is 20 µg Cu/g. All the plants' tissues contain less than 200 µg/g Zn, the toxicity level suggested by Allaway (1968). Melstead (1973) considered 300 µg/g Zn in plant tissues as the maximum concentration value for plants. Cadmium, chromium, and nickel are not considered as essential for plant growth. Melstead (1973) suggested that the maximum concentrations

TABLE 25. NUTRIENT COMPOSITION AND YIELD FOR SINGLE CUTTINGS OF NK37 BERMUDAGRASS, FORAGE SORGHUM, RESCUEGRASS AND COASTAL BERMUDAGRASS AT THE SAN ANGELO SEWAGE FARM

Crop	Acreages	Sampling Data	Cd	Cr	Cu	Ni	Zn	N	P	Protein	Yield
	ha		μg/g					%			Kg/ha
NK37 bermudagrass	14.2	750902	0.2	0.5	6.2	2.5	28	2.08	0.250	13.00	1802
			0.3	1.2	7.4	3.3	25	2.30	0.247	14.38	1502
			0.5	0.8	6.7	3.3	28	2.11	0.260	13.19	3133
Forage Sorghum	76.9	750902	0.2	0.8	6.7	2.5	35	2.23	0.343	13.94	4093
			0.3	0.8	9.1	3.0	46	1.69	0.347	10.56	4895
			0.2	<0.5	7.8	1.7	61	2.14	0.340	13.38	4300
Rescuegrass	40.5	760513	0.4	<0.5	6.7	1.2	16	2.04	0.280	12.75	6126
			0.3	<0.5	7.0	1.6	25	1.85	0.276	11.56	6194
			0.3	<0.5	7.0	1.2	23	1.98	0.276	12.38	5297
Coastal bermudagrass	127.5	760728	0.4	1.5	7.8	1.6	45	2.47	0.277	15.44	3676
			0.3	1.2	8.2	1.6	50	2.54	0.333	15.88	2974
			0.3	1.1	7.4	1.2	30	2.80	0.300	17.50	2859
Coastal bermudagrass	127.5	760810	0.4	1.1	4.5	1.6	19	1.62	0.197	10.13	5802
			0.5	1.5	3.8	4.0	10	1.71	0.200	10.69	3626
			0.3	0.7	4.2	1.6	16	1.72	0.200	10.75	8573

of Cd and Cr in plants are 3 and 2 µg/g, respectively. None of the plant tissue taken from the sewage farm had concentrations of Cd and Cr greater than that. The concentration of Ni of plant tissues was far less than 50 µg/g, the toxicity level suggested by Allaway (1968).

Several studies have shown the accumulation of trace elements in plants grown in sewage waste treated soils. In his investigation of trace element concentrations of plants grown on soil treated with sewage sludge over a period of 19 years, Le Riche (1968) found no adverse effects on crop yields, but the plants accumulated abnormally large amounts of certain trace elements. John et al. (1972) investigated the factors affecting plant uptake and phytotoxicity of Cd added to soils. They found that Cd may readily be taken up from the soil and may result in potentially hazardous accumulation of Cd in plants. Page et al. (1972) reported that plant leaves were capable of accumulating excessive amounts of Cd when the culture solution concentration was a few tenths of 1 ppm. Day and Kirkpatrick (1973) showed that wastewater generally produced equal or somewhat higher yields of grain or forage than well water with N, P, and K added equal to the N, P, and K of the wastewater. Hodgson (1970) found that the ratio of cadmium concentration in plants to that in the corresponding soil was about 10 to 1. He also showed that the ratio of total chromium in plants to that in soil was 0.02. Allaway (1968) indicated that plants may grow normally but contain levels of Cd, Mo, Ni, and Se which are toxic to animals. Plants may exclude As, Be, I, F, Zn, Ni, and others by only minimal adsorption of these trace elements from soils.

Sewage wastewaters contain certain amounts of nitrogen, phosphate, carbon, and other chemical species as well as heavy metals. The interactions between the heavy metals and all other chemical species play an important role in the fate of applied chemical elements in the soil. Agboala and Corey (1973) stated that soil phosphate level is one of four major factors which affect the availability of zinc to plants. Giordano and Mortvedt (1976) found that application of nitrogen fertilizer did not affect the downward movement of heavy metals in soil but enhanced uptake of these metals by plants. Miller et al. (1976) investigated the relationship between uptake of cadmium by soybeans and available soil phosphorus and found cadmium accumulation increased with increasingly available soil phosphorus. Williams and David (1976) reported that in a field experiment uptake by wheat of both native soil cadmium and cadmium residue from superphosphate was substantially increased by the application of ammonium nitrate. They also showed that at high levels of application, phosphate significantly affected the uptake of cadmium by plants. Caro (1974) showed the normal range of concentration of several trace elements formed in average superphosphate as follows: Cd, 50-170 ppm; Cr, 66-243 ppm; Cu, 4-79 ppm; Ni, 7-32 ppm; and Zn, 50-1430 ppm. Ozanne et al. (1976) found that phosphatic fertilizers contain appreciable amounts of zinc and play an important part in meeting the zinc requirements of plants on some Zn-deficient Australian soils.

The effects of nitrogen and phosphate fertilization and cutting on the chemical composition and yields of Coastal bermudagrass grown in the fenced plot area are listed in Table 26. The date of the first cutting of

TABLE 26. YIELD AND NUTRIENT COMPOSITION OF COASTAL BERMUDAGRASS AS INFLUENCED BY N AND P FERTILIZATION

Plot No.	Cutting	Rate of fertilizer N	Rate of fertilizer P	Plant Composition Cd	Cr	Cu	Ni	Zn	N	P	Protein	Yield
		kg/ha		ppm					%		%	kg/ha
1	1	224.4	112.2	0.3	0.1	6.7	2.8	35	2.690	0.278	16.81	9913
2	1	224.4	56.1	0.4	0.7	5.6	2.0	28	2.834	0.278	17.71	14085
3	1	0.0	0.0	0.4	0.3	5.6	1.2	30	2.683	0.263	16.77	10979
4	1	0.0	56.1	0.2	0.4	5.6	1.2	26	2.583	0.256	16.14	12202
5	1	112.2	112.2	0.3	0.7	6.4	1.6	31	2.753	0.270	17.20	11288
6	1	112.2	56.1	0.3	0.6	7.0	1.2	35	2.695	0.316	16.84	15656
7	1	112.2	0.0	0.3	0.6	6.0	2.0	31	2.650	0.313	16.56	12907
8	1	0.0	112.2	0.4	0.6	6.4	1.2	27	2.624	0.266	16.40	15263
9	1	224.4	0.0	0.4	0.7	6.7	2.0	40	2.352	0.313	14.70	14139
10	1	224.4	112.2	0.3	0.7	5.4	1.2	36	2.576	0.300	16.11	15087
11	1	0.0	112.2	0.3	0.4	10.0	1.2	35	2.476	0.323	15.47	11647
12	1	112.2	112.2	0.2	0.3	5.0	1.2	32	2.588	0.280	16.17	12893
13	1	0.0	56.1	0.3	1.0	6.7	2.4	37	3.003	0.233	18.77	12040
14	1	0.0	0.0	0.1	1.0	5.6	2.0	29	2.655	0.266	16.59	9101
15	1	224.4	0.0	0.2	1.0	5.0	2.4	37	2.683	0.280	16.77	8657
16	1	112.2	56.1	0.3	1.0	5.4	1.2	30	2.593	0.260	16.20	10405
17	1	224.4	56.1	0.3	1.2	5.0	1.2	31	2.612	0.260	16.32	7990
18	1	112.2	0.0	0.2	1.3	5.6	1.2	30	2.767	0.280	17.29	10286
19	1	224.4	56.1	0.2	1.8	6.0	1.2	28	2.841	0.280	17.75	10130
20	1	0.0	0.0	0.2	1.8	7.0	1.2	33	2.889	0.360	18.05	11078
21	1	0.0	112.2	0.3	1.8	5.6	4.0	28	2.650	0.266	16.56	7855
22	1	224.4	0.0	0.3	1.6	6.0	3.2	26	2.593	0.260	16.20	10489
23	1	112.2	0.0	0.3	1.8	6.4	2.8	24	2.514	0.260	15.71	7882
24	1	0.0	56.1	0.2	1.8	6.8	3.0	25	2.962	0.300	18.51	11444
25	1	112.2	112.2	0.3	1.6	5.4	2.8	21	2.576	0.266	16.10	9792
26	1	224.4	112.2	0.3	1.2	8.2	4.0	33	2.979	0.350	18.62	12717
27	1	112.2	56.1	0.3	1.4	8.2	2.8	33	2.151	0.330	13.44	7787
1	2	224.4	112.2	0.4	0.7	7.0	3.0	60	2.451	0.286	15.32	5647
2	2	224.4	56.1	0.1	0.8	6.7	3.4	40	2.051	0.156	12.82	6121
3	2	0.0	0.0	0.1	0.5	6.7	3.7	37	2.354	0.264	14.71	5959
4	2	0.0	56.1	0.1	0.5	6.3	3.4	34	2.236	0.213	13.98	6677
5	2	112.2	112.2	0.2	0.5	6.3	2.8	56	1.985	0.233	12.47	6893
6	2	112.2	56.1	0.1	0.5	5.7	2.8	38	1.888	0.233	11.80	8694
7	2	112.2	0.0	0.1	0.5	5.9	4.0	38	1.976	0.249	12.35	7841
8	2	0.0	112.2	0.1	0.5	6.5	3.1	48	2.054	0.276	12.84	7286
9	2	224.4	0.0	0.0	0.5	5.9	3.1	62	1.941	0.236	12.13	7950
10	2	224.4	112.2	0.1	0.5	6.1	3.1	44	1.952	0.256	12.20	8193
11	2	0.0	112.2	0.1	0.5	5.9	2.5	51	2.113	0.263	13.20	6365
12	2	112.2	112.2	0.1	0.5	5.9	3.7	40	2.057	0.256	12.85	7367
13	2	0.0	56.1	0.1	0.5	7.1	3.4	44	2.067	0.268	12.92	7625
14	2	0.0	0.0	0.1	0.5	5.7	3.1	40	2.531	0.279	15.82	5688
15	2	224.4	0.0	0.1	0.5	5.7	4.0	40	2.526	0.276	15.79	2532
16	2	112.2	56.1	0.2	0.5	5.7	3.1	38	2.464	0.276	15.40	4103
17	2	224.4	56.1	0.1	0.3	5.7	4.0	36	2.585	0.286	16.15	3724
18	2	112.2	0.0	0.0	0.3	7.9	3.1	48	2.577	0.316	16.10	4239
19	2	224.4	56.1	0.2	0.5	8.9	3.1	47	2.612	0.303	16.32	4117
20	2	0.0	0.0	0.2	0.8	5.7	3.1	37	2.365	0.276	14.78	5146
21	2	0.0	112.2	0.2	0.5	7.6	4.0	33	2.378	0.286	14.86	4469
22	2	224.4	0.0	0.1	0.5	5.7	4.3	33	2.665	0.268	16.66	6162
23	2	112.2	0.0	0.4	0.1	5.7	3.1	86	2.387	0.279	14.91	4723
24	2	0.0	56.1	0.2	0.1	7.1	4.0	93	2.494	0.276	15.58	5078
25	2	112.2	112.2	0.5	0.5	7.1	3.4	45	2.553	0.299	15.95	3914
26	2	224.4	112.2	0.1	0.3	7.5	4.0	42	2.467	0.286	15.42	4347
27	2	112.2	56.1	0.1	0.8	7.6	3.4	66	2.644	0.303	16.52	3927

Coastal bermudagrass was July 20, 1976 and the second cutting September 15, 1976. The nitrogen concentration of plant tissues of Coastal bermudagrass ranged from 1.89 to 2.98 percent. This corresponds to 11.8 and 18.6 percent crude protein in plants. The phosphorus concentration of Coastal bermudagrass varied from 0.233 to 0.350 percent. Fertilization with nitrogen and/or phosphate has no significant effect on the chemical composition and yield of Coastal bermudagrass grown in the sewage farm plots (Table 27).

San Angelo city employees have annually applied 40,000 pounds of N (as NH_4NO_3) to the forage crops. In view of the total nitrogen in the sewage effluent and high fertility of the soil from past effluent applications the practice of applying additional fertilizer N would seem highly questionable. Applications as high as 224 kg N/ha and 112 kg P_2O_5/ha did not significantly increase yield or nutrient composition of Coastal bermudagrass.

The concentrations of heavy metals (Cd, Cr, Cu, Ni, and Zn) in plants are all in the normal range reported by Allaway (1968) as discussed before. No evidence of accumulation of heavy metals in Coastal bermudagrass is observed (Table 26). There are highly significant (at 1 percent level) correlation coefficients between cutting and Cd, Cr, Ni, Zn, and N concentrations and between cutting and yields (Table 27). Cutting has a significant effect on the Cd, Cr, Ni, Zn, and N concentrations, and yields of Coastal bermudagrass (Table 27). Application of average amounts of N and P fertilizers on the sewage farm do not increase the forage yield. There was no evidence to show that accumulation of heavy metals in plants was related to impurities in the N and P fertilizers.

SOIL ANALYSIS

Introduction

Soils on the San Angelo sewage farm are from three major soil series (Angelo, Mereta, and Rioconcho). These soils belong to the great group Calciustolls which are characterized by a distinct lime ($CaCO_3$) accumulation within 1.3 m of the soil surface. Appreciable amounts of montmorillonite and mixed clay minerals are found in the soils. These red to brown soils, formed in outwash, clayey to silty red bed, or over limestone in the Rolling Plains in Central Texas, are classified as Mollisols (suborder).

The Angelo soil is well drained, and surface runoff is slow. This calcareous soil has a distinct zone of calcium carbonate accumulation at a depth of about 70 cm. The permeability is moderately slow, and the available water capacity is high. The soil profile can be distinguished by the following horizons: Ap, B21, B22, $B23_{Ca}$, and C. The Angelo solum thickness is 150 to 300 cm. Angelo soils are deeper than the Mereta soils but lack an indurated zone of calcium carbonate accumulation. These are productive soils when used for crops and as rangeland.

TABLE 27. STATISTICAL ANALYSIS SHOWING THE EFFECT OF N AND P FERTILIZATION ON PLANT COMPOSITION AND YIELDS OF COASTAL BERMUDAGRASS GROWN IN THE SEWAGE FARM

Effect	N	P	Cd	Cr	Cu	Ni	Zn	Yield
	A. Correlation coefficients and significant probability level							
N fertilizer	0.0236	0.1556	0.0198	0.0048	−0.0934	0.0985	0.0182	−0.0248
	0.865	0.261	0.886	0.972	0.501	0.478	0.895	0.858
P fertilizer	−0.0944	0.0724	0.1585	−0.1151	0.2325	0.0022	−0.0066	0.1002
	0.497	0.602	0.252	0.407	0.090	0.986	0.961	0.470
Cutting	−0.6293	−0.2215	−0.5985	−0.5561	0.1173	0.7019	0.6041	−0.8143
	0.000	0.107	0.000	0.000	0.398	0.000	0.000	0.000
	B. Values of F test							
Cutting	29.47[a]	2.39	25.35[a]	18.31[a]	0.67	43.82[a]	25.34[a]	77.84[a]
N fertilizer	0.68	0.67	0.24	0.00	0.33	0.85	0.12	0.08
P fertilizer	0.53	0.20	1.19	0.55	1.49	0.24	0.01	0.60
N and P fertilizers	0.63	1.19	0.19	0.18	0.77	0.97	0.81	0.36
Cutting and N	0.40	0.28	0.30	0.03	0.36	0.02	0.58	0.19
Cutting and P	0.49	0.18	0.52	0.70	0.22	0.61	0.06	0.14
Cutting and N and P	0.55	0.72	0.80	0.40	1.04	0.45	0.82	0.01

[a] significant at 1% level

The Mereta soils are well drained, and the surface runoff is slow. The available water capacity is low and limits vegetative production. They have indurated caliche at less than 50 cm depth. The surface layer is dark brown or dark grayish brown clay loam about 30.48 cm thick. The Mereta series is located in the level to gently sloping parts of the outwash plains of Tom Green County. The soil profile can be distinguished by the following horizons: Ap, A12, A13, $C1_{Cam}$, $C2_{Ca}$, and C_3. The indurated caliche is located in the C_{1Cam} horizon (45 to 54 cm depth). The indurated caliche horizon may have roots and a little soil in the cracks and between plates. It contains a few to 10 percent by volume of caliche fragments less than 2.54 cm in diameter. The Mereta solum thickness ranges from 35 to 50 cm. Land leveling, terracing, and depth of plowing are limited by the shallow depth of hard caliche.

The Rioconcho soils are well drained, and surface runoff is slow. The permeability is moderately slow, and the available water capacity is high. The Rioconcho series is located in the alluvial flood plain of streams draining limestone areas. The surface layer is dark grayish brown clay loam about 95 cm thick. The thickness of Rioconcho soils over gravel, sand, or limestone ranges from 180 to 600 cm. Only three soil horizons (A11, A12, and C) can be distinguished in the Rioconcho soil profile. The thickness of the Dark A horizon ranges from 51 to 127 cm. These soils are well suited for cropland and are frequently irrigated. Flooding occurs once in 3 to 20 years but seldom lasts for more than 1 day.

Initial Characterization of Physical and Chemical Properties

Initially a total of 180 surface soil samples were analyzed for organic matter, carbonate, cation exchange capacity, total phosphorus, water soluble phosphate, total nitrogen, and 1N HCl extractable Cd, Cr, Cu, Ni, Pb, and Zn. These surface samples were taken from the 3 soil series located on the sewage farm.

The chemical and physical properties of these three sewage farm soil series compiled from samples taken to a depth of 30 cm are listed in Table 28.

Texture

Rioconcho and Angelo soils had more than 38 percent clay in the upper 40 cm of the soil profile. Mereta soil had a clay content ranging from 27 to 35 percent. Angelo and Mereta soils are classified as clay loams and Rioconcho as clay.

Soil pH

The pH value of all three soils in 1:1 soil-water solution is greater than 7.6.

TABLE 28. CHEMICAL AND PHYSICAL PROPERTIES OF THE TOP 40 CM OF THREE MAJOR SOIL SERIES FROM THE SAN ANGELO SEWAGE FARM

Soil Series	Depth	Sand	Silt	Clay	Texture Class	Bulk Density	pH		Carbonate	Organic Matter	Cation Exchange Capacity	Soluble Salt
							H_2O	0.01 M $CaCl_2$	$CO_3^=$-C			
	cm	%				gm/cm³			%	%	meq/100g	µmhos/cm
Rioconcho	0-5	20.8	36.2	42.9	clay	1.37	7.64	7.20	2.59	3.16	17.43	720
	5-10	19.7	34.4	45.8	clay	1.31	7.70	7.08	2.72	1.91	16.25	620
	10-20	17.2	36.4	46.3	clay	1.20	7.67	7.05	2.76	1.39	15.87	770
	20-30	18.8	34.1	46.9	clay	1.21	7.75	7.05	1.94	1.18	16.61	710
	30-40	18.3	34.4	47.3	clay	1.22	7.84	7.11	2.09	1.18	16.49	660
Angelo	0-5	36.2	26.0	37.8	clay loam	1.32	8.17	7.65	1.81	2.53	23.12	273
	5-10	37.5	24.7	37.8	clay loam	1.15	8.34	7.67	1.90	2.44	24.22	252
	10-20	36.2	26.1	37.7	clay loam	1.23	8.54	7.75	2.01	1.94	21.50	200
	20-30	33.7	26.3	40.0	clay loam	1.23	8.76	7.82	2.54	1.40	17.26	179
	30-40	36.2	24.5	39.3	clay loam	1.21	8.33	7.88	4.22	1.13	15.52	183
Mereta	0-5	45.8	27.1	27.1	clay loam	1.37	7.87	7.45	[illegible]33	3.36	20.90	399
	5-10	43.1	28.5	28.4	clay loam	1.58	8.02	7.53	1.55	2.25	17.29	315
	10-20	45.9	25.2	28.9	clay loam	1.45	8.10	7.85	1.50	1.85	16.00	273
	20-30	43.2	25.9	30.9	clay loam	1.44	8.06	7.59	1.79	1.67	16.53	252
	30-40	39.2	26.2	34.6	clay loam	1.43	8.30	7.71	5.50	1.16	10.95	252

Organic Matter

The organic matter content of all three soils in the upper 5 cm ranges from 2.5 to 3.4 percent and drops to about 1.1 percent below 30 cm depth. Prasad et al. (1976) found that in alkaline and calcareous soils natural chelating agents play an important role in the self-diffusion of zinc. In his study of 75 pasture soils of Spain, Macias (1973) found a significant positive correlation (5 percent level) between organic matter and total zinc and between organic matter and 1N NH_4OAc extractable Cu. He found a negative correlation, significant at the 5 percent level, between organic matter and 0.1 N HCl extractable Cu. Martens (1968) suggested that Cu bonded to organic matter is the main source of plant available Cu. John (1972) reported that extractable zinc in soil is increased with higher organic matter and is one of the important soil properties in predicting the zinc content of corn and oat plants.

Carbonate

All three sewage farm soils have free $CaCO_3$ throughout the profile. Angelo and Mereta soils have high carbonate content (4.22 and 5.50 percent CO_3-C, respectively) at a soil depth between 30 to 40 cm. The average carbonate content of 120 sewage farm surface soils is 1.78 ± 0.68 percent as $CO_3^{=}$-C. In their study of zinc adsorption by calcareous soils, Udo et al. (1970) found that the carbonate equivalent and organic matter content of the soil influenced the Langmuir adsorption maxima of zinc by calcareous soils. Griffin and Shrimp (1976) reported that both cation exchange capacity and carbonate precipitates were the principal mechanisms affecting metal attraction by clay minerals in landfill leaching. Ellis (1974) stated that after prolonged wastewater applications most of the heavy metals will be expected to precipitate as a hydroxide or a carbonate in the soil with a pH greater than 7.0.

Cation Exchange Capacity

The cation exchange capacity of Mereta soil ranges from 20.90 meq/100 g at the surface to 10.95 meq/100 g at the 30-40 cm depth. Angelo soils have the highest average cation exchange capacity (ranging from 24.22 to 15.52 meq/100 g) of the three soils. The cation exchange capacity of Rioconcho soils ranges from 17.43 to 16.49 meq/100 g. The cation exchange capacity of 120 surface soils at the sewage farm was 18.4 ± 4.1 meq/100 g. The cation exchange capacity is significantly different at the 1 percent level from that of 60 surface soils from the control area (20.2 ± 3.6 meq/100 g) as shown in Table 29. Haghiri (1974) found the plant uptake of cadmium could be influenced by several factors such as organic matter and cation exchange capacity. Korte et al. (1976) studied the influence of soil chemical properties on trace element movement in soils of 7 major orders. They found significant correlations between cation exchange capacity and adsorption of Ni and Zn by soils. No significant correlation between cation exchange capacity and adsorption of Cd and Cr was observed. They concluded that the value of cation exchange capacity for predictive purposes with natural soils is limited. There was a highly significant difference at the 1 percent level in cation exchange capacity of surface

TABLE 29. STATISTICAL ANALYSIS OF SURFACE SOIL CHEMICAL CHARACTERISTICS BY F TEST*

Effect	Organic matter	Carbonate	Cation Exchange Capacity	Water Soluble P	Total P	Total N	1N HCl extractable Cd	Cr	Cu	Pb	Ni	Zn
Soil Series (A)	0.26	18.52[c]	9.32[c]	6.69[c]	2.54[a]	1.45	10.86[c]	5.63[c]	3.89[b]	1.77	23.24[c]	2.38[a]
Wastewater treatment (B)	0.03	3.30[a]	9.20[c]	417.78[c]	118.23[c]	0.27	14.28[c]	4.46[b]	0.15	1.89	0.46	1.54
Soil Depth (C)	11.83[b]	7.32[c]	2.91[b]	1.06	18.58[c]	10.49[c]	3.62[b]	5.82[c]	2.46[a]	2.37[a]	1.82	1.78
A, B interaction	2.61[a]	40.23[c]	0.01	0.69	12.17[c]	3.04[a]	8.89[c]	4.15[b]	2.21	0.71	16.44[c]	1.10
A, C interaction	0.49	1.73	0.40	0.62	0.93	0.62	1.43	0.96	0.99	1.25	0.29	1.50
B, C interaction	2.57[a]	0.12	1.73	0.17	8.50[c]	2.63[a]	1.32	2.49[a]	0.75	1.06	0.89	0.86
A, B, C interaction	0.55	0.46	0.84	0.28	0.79	0.62	1.44	0.50	0.42	0.56	0.97	0.73

[a]significant at 10 percent level

[b]significant at 5 percent level

[c]significant at 1 percent level

*180 surface soil samples are used for calculation

soils among three soil series. The difference in cation exchange capacity at varying soil depths is significant at the 5 percent level.

Soil Salinity

The amount of soluble salt in all three soils is low, and no salinity effect on plants is expected. The conductivity of a saturated paste extract was less than 1 mmho/cm.

Statistical Relationships Between Surface Soil Properties

The effects of soil series, wastewater treatment, and soil depth on the soil chemical characteristics were analyzed statistically and are listed in Table 29. Partial correlation coefficients among the 12 soil chemical parameters are calculated and listed in Table 30. These partial correlation coefficients will be used to evaluate the best relationships among all 12 soil characteristics.

It was found that wastewater treatment and soil series have no effect on the soil organic matter content; whereas soil depth has a significant effect at the 5 percent level. Partial correlation coefficients among soil organic matter and total nitrogen, total phosphorus, and cation exchange capacity are highly significant at the 0.1 percent level (Yp = 0.985, 0.585, and 0.569, respectively).

There was a significant difference at the 10 percent level between the carbonate content of soils in the sewage farm and that of the control area. It was found that soil series, soil depth, and interaction of soil series and wastewater treatment have a highly significant (at the 1 percent level) effect on the carbonate content of these surface soils (Table 29). A highly significant negative partial correlation at the 1 percent level between carbonate content and HCl extractable Ni, Cu, Cr (Yp = -0.504, -0.233, and -0.337, respectively), and between carbonate content and cation exchange capacity (Yp = -0.213) was found.

1N HCl Extractable Heavy Metals

Lagerwerff (1971) showed that a chemical index using 1N HCl as an extractant could be used to examine the availability of heavy metals to the plants. He found that increasing the soil pH from 5.9 to 7.2 resulted in decreases in yield and heavy metal content of the radish plant. Average concentrations of 1N HCl extractable Cd, Cr, Cu, Ph, Ni and Zn are presented in Table 30 for the San Angelo sewage farm and the control area soil.

Data presented in Table 29 show that irrigation of land with sewage wastewater can significantly affect the acid extractable Cd and Cr in the surface soils. No significant effect of wastewater irrigation on 1N HCl extractable Cu, Pb, Ni, and Zn of soils is observed. The average 1N HCl extractable Cd and Cr concentration of 120 surface soils at the sewage farm was 0.48 ± 0.22 and 0.49 ± 1.09 µg/g, respectively, and that of 60 surface soils in the control area was 0.38 ± 0.07 and 0.21 ± 0.22 µg/g, respectively. Application of sewage wastewater on land significantly increased the acid

TABLE 30. AVERAGE CONCENTRATIONS OF 1N HCl EXTRACTABLE Cd, Cr, Cu, Pb, Ni, and Zn IN THREE SOIL SERIES FROM THE SAN ANGELO SEWAGE FARM AND THE CONTROL AREA

Elements		Rioconcho		Angelo		Mereta	
		Sewage farm[a]	Control farm[b]	Sewage farm[a]	Control farm[b]	Sewage farm[a]	Control farm[b]
		µg/g					
Cd	Mean	0.38	0.38	0.46	0.41	0.60	0.35
	Standard Deviation	0.07	0.06	0.05	0.04	0.34	0.08
	Maximum	0.50	0.45	0.54	0.48	2.40	0.46
	Minimum	0.28	0.17	0.36	0.36	0.36	0.21
Cr	Mean	0.13	0.11	0.90	0.09	0.43	0.42
	Standard Deviation	0.21	0.05	1.40	0.11	1.15	0.26
	Maximum	0.81	0.14	7.05	0.26	6.56	0.65
	Minimum	0.00	0.00	0.00	0.00	0.00	0.00
Cu	Mean	0.55	0.50	1.13	0.52	1.04	1.48
	Standard Deviation	0.07	0.06	1.09	0.12	2.45	0.74
	Maximum	0.78	0.52	5.22	1.02	15.82	2.51
	Minimum	0.47	0.25	0.47	0.47	0.45	0.46
Pb	Mean	4.76	4.68	17.75	5.38	36.61	7.03
	Standard Deviation	1.44	0.76	34.17	1.07	133.90	2.76
	Maximum	8.67	5.69	208.64	8.99	833.36	16.67
	Minimum	3.09	2.28	3.12	4.71	4.09	4.15
Ni	Mean	2.04	1.71	2.46	2.01	2.38	3.00
	Standard Deviation	0.27	0.20	0.58	0.42	0.67	0.72
	Maximum	2.89	1.80	3.33	3.12	5.05	4.19
	Minimum	1.79	0.87	1.82	1.66	1.74	1.87
Zn	Mean	0.73	0.41	5.48	0.48	45.72	1.64
	Standard Deviation	0.63	0.07	8.26	0.39	178.56	1.06
	Maximum	2.89	0.47	39.02	1.97	1096.60	4.04
	Minimum	0.37	0.21	0.33	0.31	0.35	0.29

[a] from a total of 40 samples.

[b] from a total of 20 samples.

extractable Cd and Cr concentrations in these soils. There is a highly significant partial correlation at the 1 percent level between any one of these acid extractable heavy metals (Cr, Cd, Cu, Pb, Ni and Zn) and other heavy metals (Table 31). The partial correlation coefficients (a total of 15 Yp) between these six 1N HCl extractable heavy metals ranges from 0.427 to 0.970. The 1N HCl extractable Zn, Pb, and Cd are highly correlated with total soil nitrogen. There is significant partial correlation (at 5 percent level) between acid extractable Cd and total soil phosphorus, and between acid extractable Cu and total soil nitrogen. Water soluble phosphorus is significantly correlated at the 1 percent level with acid extractable Cd, Cr, Cu, Ni, Pb, and Zn.

A highly significant partial correlation was found between organic matter content and 1N HCl extractable Zn and Cd concentrations (Yp = 0.206 and 0.290, respectively). Some heavy metals are expected to be retained in the soil by organic matter. Many organic materials are capable chelating the heavy metals and increase their concentration in soil solution. This will result in increased uptake by plants and increased leaching through the soil profile into the groundwater (Ellis 197

There was a highly significant positive partial correlation ... the 1 percent level between cation exchange capacity and HCl-extractable Ni (Yp = 0.205), total N(Yp = 0.546), total P(Yp = 0.440), and water soluble phosphorus (Yp = 0.260 (Table 31).

NUTRIENT LOADING OF SOIL PROFILES

Soil cores were taken from the sewage farm and from a control area adjacent to the farm. Sampling areas were chosen that represented the major soil series (Angelo, Mereta and Rioconcho). Ten cores were taken on the farm where sewage effluent has been applied for the past 18 years. Five cores were taken from the control area which had been grazed but had not been cultivated or received sewage effluent. Soils were taken to a depth of 200 cm, except where a gravel or hard caliche layer existed in the soil profile. The location of cores from the sewage farm and from the control area is shown in Figure 10. The cores were sectioned and each section analyzed for total nitrogen, NH_4^+-N, NO_2^--N, NO_3^--N, total P, water-soluble P and total heavy metals (Cd, Cr, Cu, Pb, Ni, and Zn). A comparison of the two sets of profile samples were used to assess the nutrient loading which occurred as a result of sewage effluent irrigation. The total nutrient contents were calculated using the concentration of total nutrients and soil bulk density at each depth. Because only two soil profiles, one in the sewage farm and another one in the control area, from each soil series have been used for the determination of bulk density and that value of bulk density has been used for all soil profiles of the same soil series, the total soil nutrient contents are only an estimate. The bulk densities of three soil series from the San Angelo sewage farm and the control area are shown in Table 32.

TABLE 31. PARTIAL CORRELATION COEFFICIENTS AND SIGNIFICANT PROBABILITY LEVEL OF CHEMICAL CHARACTERISTICS OF SURFACE SOILS (0 - 20 cm) IN THE SEWAGE FARM AND THE CONTROL AREA *

	Organic Matter	Carbonate	Cation Exchange Capacity	H_2O-P	Total-P	Total-N	HCl-Cd	HCl-Cr	HCl-Cu	HCl-Ni	HCl-Pb
HCl-Zn	0.20625 0.009	−0.09328 0.245	−0.04209 0.600	0.38285 0.000	0.06823 0.428	0.26073 0.001	0.90283 0.000	0.54849 0.000	0.90141 0.000	0.96953 0.000	0.46173 0.000
HCl-Ni	0.07681 0.338	−0.50388 0.000	0.20542 0.009	0.27360 0.000	−0.10904 0.211	0.08934 0.265	0.42692 0.000	0.63813 0.000	0.61230 0.000	0.49921 0.000	
HCl-Pb	0.16246 0.042	−0.13023 0.104	−0.03111 0.698	0.39035 0.000	0.05179 0.519	0.20327 0.010	0.85783 0.000	0.69533 0.000	0.94989 0.000		
HCl-Cu	0.15778 0.048	−0.23309 0.003	0.05980 0.456	0.40938 0.000	0.04108 0.605	0.19166 0.016	0.76194 0.000	0.78387 0.000			
HCl-Cr	0.12401 0.121	−0.33724 0.000	0.16261 0.041	0.33240 0.000	0.07566 0.346	0.11919 0.137	0.44750 0.000				
HCl-Cd	0.28989 0.000	0.03603 0.654	−0.07230 0.368	0.30061 0.000	0.19827 0.012	0.33983 0.000					
Total-N	0.98547 0.000	−0.02288 0.776	0.54676 0.000	0.27291 0.000	0.60671 0.000						
Total-P	0.58451 0.000	0.15205 0.057	0.44030 0.000	0.25942 0.001							
H_2O-P	0.24841 0.001	−0.11978 0.135	0.26001 0.001								
Cation Exchange Capacity	0.56912 0.000	−0.21312 0.007									
Carbonate	−0.02237 0.780										

*From 180 soil samples

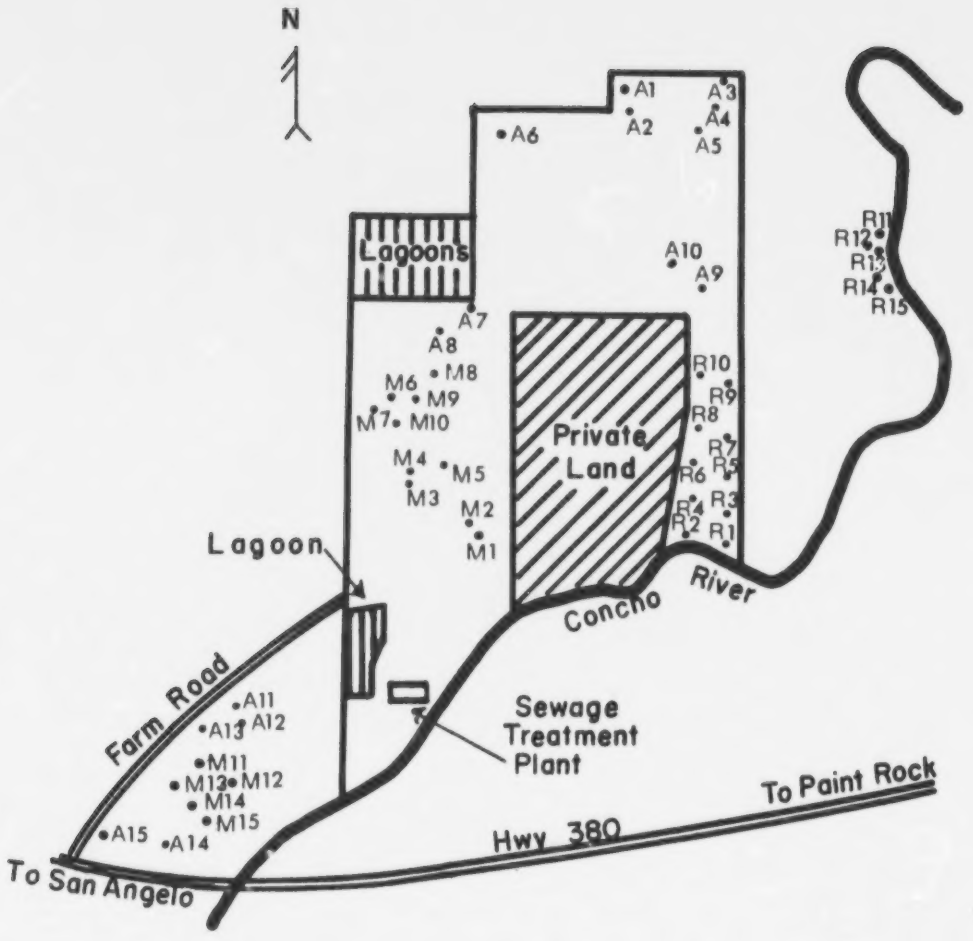


Figure 10. Sampling locations for soil cores taken from the sewage farm and for soil cores taken from the control area outside the sewage farm (A = Angelo, M = Mereta, R = Rioconcho).

TABLE 32. DISTRIBUTION OF BULK DENSITY WITH DEPTH IN THREE SOIL SERIES FROM THE SAN ANGELO SEWAGE FARM AND THE CONTROL AREA

Location	Depth	Bulk density[a]		
		Rioconcho	Angelo	Mereta
		---------- g/cm^3 ----------		
Sewage farm	0-5	1.37	1.36	1.32
	5-10	1.31	1.58	1.15
	10-15	1.23	1.39	1.37
	15-20	1.18	1.50	1.08
	20-30	1.21	1.44	1.23
	30-40	1.22	1.43	1.21
	40-50	1.31	1.42	1.22
	50-100	1.31	1.38	—
Control area	0-5	1.18	1.25	1.36
	5-10	1.26	1.07	1.34
	10-15	1.20	1.10	1.42
	15-20	1.26	1.01	1.43
	20-30	1.25	1.20	1.49
	30-40	1.28	1.14	1.50
	40-50	1.38	1.13	1.62
	50-100	1.21	1.23	—

[a]from a single measurement

Total Nitrogen

The total nitrogen (N) concentration ranges from 0.06 to 0.5 percent in the top 15 cm of most cultivated soils. Most of the total N is in the organic form. Ammonification and nitrification of organic N may significantly increase the NH_4^+-N, NO_2^--N, and NO_3^--N concentrations in the soil solution. Irrigation with wastewater on land may become a potential environmental hazard if the crop removal of applied N is small, and the applied N leaches into the surface or ground waters.

A study by Johnson et al. (1975) indicated that growing soybeans resulted in a net removal of N from the soil, especially when the soil contained residual inorganic N from a preceding crop. Stanford (1973) reported that with good management the grain and stover of corn could recover 50 to 70 percent of the applied N. He showed that if optimum rates of N were applied on corn, all residual N would be immobilized. Immobilization of applied N by microorganisms and plants will reduce the potential of leaching of N and removals of N on cropland in 8 Great Plains and Western States in the United States. They found that the weighted average of the ratio N fertilizer applied to nitrogen removed was 0.82 for this region. This ratio for other states in Central, East, and Southeast regions of the United States ranged from 0.59 to 4.90.

The distribution of total N concentration with depth in the sewage farm soils compared to the control area is shown in Figure 11. The maximum total N concentration was found in the top 0-5 cm layer and generally decreased with increased soil depth in all soils. There is a significant difference (at the 1 percent level) in total N concentrations among the three soil series and among soils at varying depths (Table 33). No significant difference is found in total N concentration between the sewage farm soils and the control area soils or among the soil cores sampled. Irrigation with sewage wastewater did not significantly change the total N concentration of Rioconcho, Angelo, and Mereta soils. In Rioconcho soils removal of applied N is greater than the N applied to the soil. In Angelo and Mereta soils there is an accumulation of total N in the upper 0-5 cm of surface soil. The total N content at varying soil depths in the soil profile in Rioconcho, Angelo, and Mereta soils is listed in Tables 34, 35, and 36, respectively. The average total N content of the upper 20 cm of soil increased 38.9 percent in Angelo soils, and 26.6 percent in Mereta soils after 18 years of wastewater irrigation and crop production (Table 37). This increase was due primarily to an accumulation in the top 0-5 cm. There was a decrease of 19.6 percent of total N content in the top 20 cm soil column in Rioconcho soils. Total N content was less for the Rioconcho soils in the sewage farm at all depths. The overall average total N content of the top 20 cm of soil in these three soil series increased 13.4 percent.

Exchangeable Inorganic Nitrogen

Ammonium (NH_4^+) and nitrate (NO_3^-) are the most important forms of N utilized for plant growth. Generally, only a small proportion of total soil N is in the inorganic forms, if the nonexchangeable NH_4^+ fixed by soil

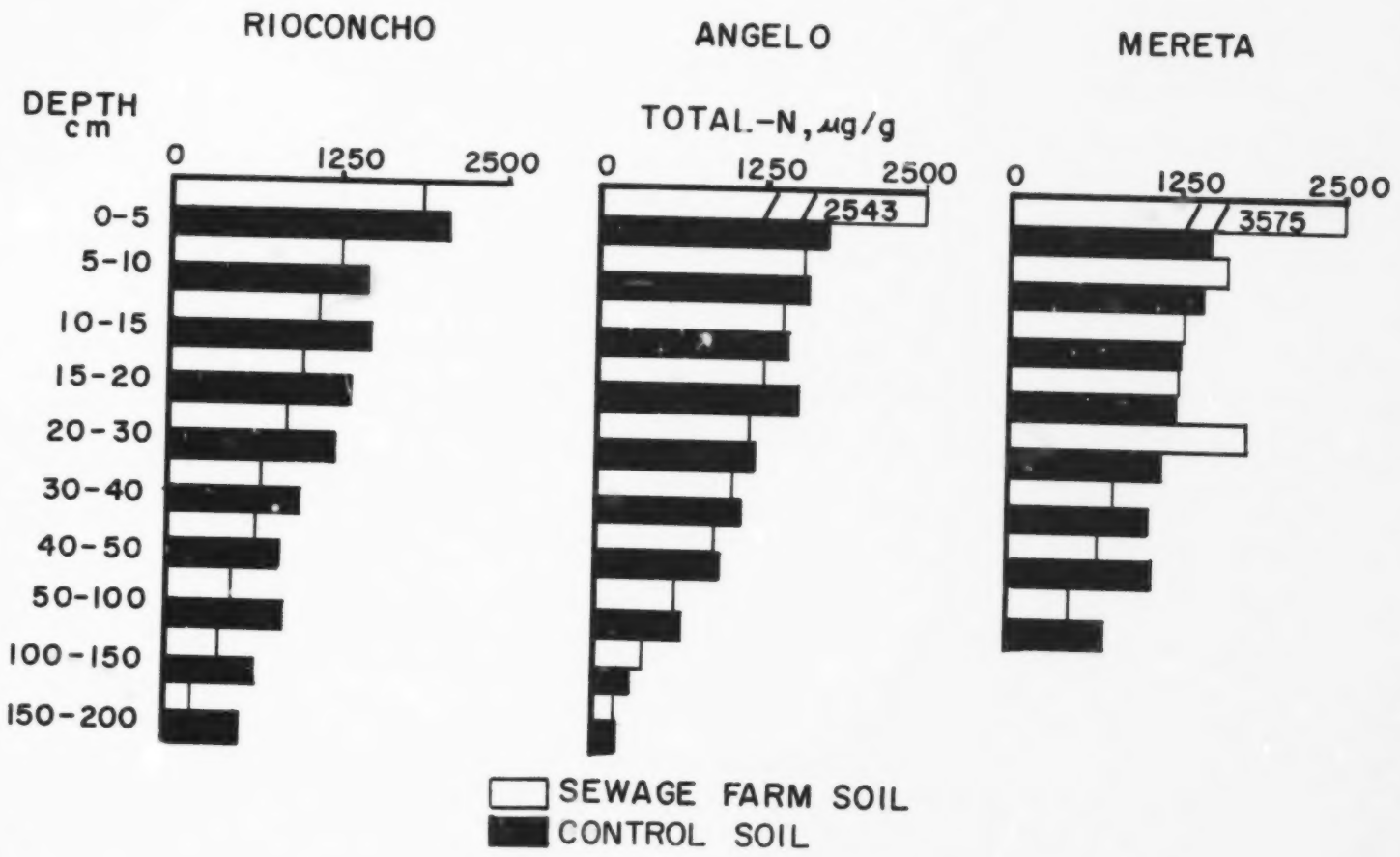


Figure 11. The effect of sewage effluent irrigation on total nitrogen content of the top 200 cm of soil from the sewage farm compared to the control area.

TABLE 33. STATISTICAL RELATIONSHIPS BETWEEN SOIL NUTRIENTS AS RELATED TO SOIL SERIES, TREATMENT, CORE AND DEPTH AS DETERMINED BY F TEST

Effect	Total-N	NO_3^--N	NO_2^--N	NH_4^+-N	Total-P	H_2O-P	Cd	Cr	Cu	Ni	Pb	Zn
Soil Series	7.08[c]	7.86[c]	1.66	2.19	5.26[c]	2.25	12.99[c]	1.19	2.28	126.55[c]	28.58[c]	5.31[c]
Treatment	0.09	12.05[c]	0.46	0.10	127.37[c]	528.16[c]	2.10	5.99[b]	3.29[a]	57.61[c]	11.46[c]	2.19
Core	0.82	5.80[c]	1.28	2.14[b]	3.06[c]	7.30[c]	2.76[c]	1.71[a]	5.29[c]	3.96[c]	2.49[c]	1.73[a]
Depth	17.42[c]	1.04	0.86	0.62	22.60[c]	13.48[c]	19.44[c]	1.67[a]	0.59	24.33[c]	0.80	1.72[a]

[a]Significant at 10% level

[b]Significant at 5% level

[c]Significant at 1% level

[d]From 408 Soil Samples

TABLE 34. DISTRIBUTION OF NUTRIENTS WITH DEPTH IN RIOCONCHO SOIL CORES TAKEN FROM THE SEWAGE FARM AND FROM AN ADJACENT CONTROL AREA

Depth	Total-P	H_2O-P	Total-N	NO_3^--N	NO_2^--N	NH_4^+-N	Cd	Cr	Cu	Ni	Pb	Zn
	Kg/ha											
						SEWAGE FARM						
0-5	763.77	15.99	1298.76	7.69	0.07	0.54	0.73	15.35	8.12	9.35	15.20	30.14
5-10	569.19	14.47	831.85	6.39	0.05	0.85	0.71	13.78	7.75	8.86	13.87	26.57
10-15	486.46	13.06	698.02	7.06	0.06	0.86	0.65	12.86	7.76	8.25	12.34	24.65
15-20	43[illegible].65	11.76	600.62	5.95	0.04	1.00	0.63	12.40	8.04	8.02	11.12	23.64
20-30	861.52	22.13	1090.21	16.28	0.09	0.60	1.34	25.05	16.15	16.69	21.93	46.25
30-40	824.72	20.38	883.28	13.84	0.09	0.00	1.41	24.96	18.62	17.05	22.70	46.61
40-50	839.71	20.18	877.70	11.59	0.09	0.52	1.53	26.10	21.47	19.00	25.02	50.30
50-100	3668.00	63.79	3530.45	50.56	0.48	2.62	8.18	131.00	219.29	98.44	122.94	303.65
						CONTROL AREA						
0-5	401.79	2.25	1227.20	4.55	0.13	0.41	0.80	9.92	6.33	8.64	12.70	27.09
5-10	412.02	1.48	1255.59	5.24	0.24	0.00	0.84	11.17	7.06	9.75	13.41	29.85
10-15	376.20	0.86	915.60	3.27	0.11	0.00	0.82	10.12	6.54	9.33	12.83	26.37
15-20	377.37	0.72	869.40	6.91	0.14	1.07	0.86	10.59	7.16	9.78	13.60	27.09
20-30	696.25	1.47	1585.00	10.80	0.22	1.62	1.73	21.31	13.81	19.63	27.55	48.85
30-40	661.76	1.33	1288.96	4.50	0.19	3.20	1.71	20.31	13.35	19.96	25.12	53.64
40-50	673.44	1.25	1188.18	3.56	0.19	0.00	1.84	20.17	13.09	20.87	25.84	54.42
50-100	3043.15	4.29	5541.80	17.54	0.87	0.00	8.77	97.22	66.24	98.61	122.45	250.14

TABLE 35. DISTRIBUTION OF NUTRIENTS WITH DEPTH IN ANGELO SOIL CORES TAKEN FROM THE SEWAGE FARM AND FROM AN ADJACENT CONTROL AREA

Depth	Total-P	H_2O-P	Total-N	NO_3^--N	NO_2^--N	NH_4^+-N	Co	Cr	Cu	Ni	Pb	Zn
	Kg/ha											
						SEWAGE FARM						
0-5	1024.76	11.27	1723.12	14.17	0.10	1.29	0.55	16.23	8.16	9.73	25.34	37.58
5-10	842.93	12.91	1231.61	7.77	0.08	0.23	0.69	15.71	8.80	11.82	25.58	39.69
10-15	548.35	12.22	987.59	5.11	0.07	0.00	0.63	14.57	7.51	10.73	19.78	32.40
15-20	513.75	13.62	967.50	5.07	0.08	1.05	0.67	14.40	7.88	11.56	18.89	33.36
20-30	915.84	24.71	1696.32	9.70	0.18	1.58	1.42	27.87	14.84	24.04	26.79	58.63
30-40	898.04	21.95	1468.61	7.65	0.18	0.71	1.63	24.78	14.85	26.21	26.52	55.02
40-50	866.20	18.80	1324.86	7.51	0.15	2.13	1.86	25.27	14.73	26.83	28.44	52.44
50-100	3346.50	80.17	4319.40	26.97	0.71	6.21	11.79	102.60	66.17	138.82	142.55	226.66
						CONTROL AREA						
0-5	247.50	0.50	1093.75	2.66	0.21	4.37	0.74	9.43	7.78	10.59	11.25	20.28
5-10	219.88	0.32	859.21	2.16	0.23	3.63	0.62	8.20	6.72	9.25	9.15	23.74
10-15	206.80	0.26	799.70	2.29	0.14	2.42	0.65	9.27	6.12	9.71	9.42	23.75
15-20	181.29	0.33	783.25	2.85	0.13	3.28	0.64	9.27	5.67	9.46	8.96	21.46
20-30	423.60	0.74	1452.00	6.84	0.38	8.76	1.57	25.06	13.46	22.99	22.04	51.19
30-40	384.18	0.49	1295.04	7.22	0.26	6.15	1.53	24.48	12.22	22.68	21.32	49.12
40-50	360.47	0.35	1111.92	7.07	0.26	7.57	1.71	22.37	11.96	23.53	21.78	48.90
50-100	1906.50	0.73	4040.55	52.02	1.46	27.67	11.80	88.31	62.11	134.43	132.77	218.57

TABLE 36. DISTRIBUTION OF NUTRIENTS WITH DEPTH IN MERETA SOIL CORES TAKEN FROM THE SEWAGE FARM AND FROM AN ADJACENT CONTROL AREA

Depth	Total-P	H_2O-P	Total-N	NO_3^--N	NO_2^--N	NH_4^+-N	Cd	Cr	Cu	Ni	Pb	Zn
	kg/ha											
SEWAGE FARM												
0-5	1180.74	14.66	2333.10	20.98	1.37	26.26	1.00	42.27	21.33	9.39	268.75	204.07
5-10	733.70	10.49	980.95	15.08	0.08	0.46	0.73	13.98	9.49	8.17	118.62	57.28
10-15	669.93	12.02	940.50	35.66	8.29	19.52	0.80	13.45	9.16	10.40	135.63	41.40
15-20	438.48	9.04	695.52	11.94	0.08	0.54	0.72	9.48	6.81	8.62	115.50	27.01
20-30	836.40	15.32	2277.96	23.37	0.13	0.00	2.17	23.03	14.77	22.69	225.09	67.28
30-40	655.82	14.37	975.26	23.58	0.13	0.60	2.27	16.26	10.75	22.66	438.38	40.02
40-50	642.94	14.56	810.08	24.32	0.16	1.22	2.54	15.15	9.79	23.42	230.58	34.41
CONTROL AREA												
0-5	212.84	0.33	1024.08	0.88	0.05	0.40	0.53	10.15	6.70	9.22	9.87	28.85
5-10	214.40	0.14	982.22	0.57	0.07	0.00	0.51	10.31	7.14	9.82	8.64	26.51
10-15	250.63	0.19	959.92	1.10	0.22	0.63	0.57	11.16	7.40	10.74	8.97	27.48
15-20	255.97	0.18	945.23	1.24	0.08	0.00	0.65	11.57	7.60	11.92	9.76	27.34
20-30	505.11	0.46	1737.34	2.17	0.06	1.19	1.63	24.68	14.91	25.01	21.96	53.95
30-40	535.50	0.42	1638.00	2.07	0.14	1.05	1.89	26.38	15.51	26.34	23.20	55.77
40-50	596.16	0.37	1814.40	3.28	0.18	2.43	2.13	28.80	17.82	30.52	26.70	62.03

Table 37. TOTAL NUTRIENT CONTENTS OF THE TOP 20 CM SOIL SOLUMS FROM THE SAN ANGELO SEWAGE FARM AND THEIR RELATIVE CHANGE AFTER 18 YEARS OF IRRIGATION WITH SEWAGE EFFLUENT COMPARED TO AN ADJACENT CONTROL AREA

	RIOCONCHO				ANGELO				MERETA				ALL SOILS	
Nutrient	Sewage farm	Control area	Difference		Sewage farm	Control area	Difference		Sewage farm	Control area	Difference		Difference	
	Kg/ha			%	Kg/ha			%	Kg/ha			%	Kg/ha	%
Total-P	2253.09	1567.38	685.71	43.7	2929.80	855.48	2074.32	242.5	3022.85	933.84	2089.01	223.7	4849.04	144.5
H_2O-P	55.30	5.34	49.96	935.6	50.04	1.43	48.61	3399.3	46.23	0.86	45.37	5275.6	143.94	1886.5
Total-N	3429.26	4267.79	-838.53	-19.6	4909.83	3535.92	1373.91	38.9	4950.08	3911.45	1038.63	26.6	1574.01	13.4
NO_3^--N	27.11	19.99	7.12	35.6	32.13	9.98	22.15	221.9	83.68	3.81	79.87	2096.3	109.14	323.1
NO_2^--N	0.24	0.65	-0.41	-63.1	0.35	0.74	-0.39	-52.7	9.85	0.44	9.41	2138.6	8.61	470.5
NH_4^+-N	3.26	1.48	1.78	120.3	2.58	13.72	-11.14	-81.2	46.79	1.05	45.74	4356.2	36.38	223.9
Total-Cd	2.73	3.34	-0.61	-18.3	2.55	2.67	-0.12	-4.5	3.28	2.29	0.99	43.2	0.26	3.1
Total-Cr	54.41	41.82	12.59	30.1	60.92	36.77	24.15	65.7	79.20	43.22	35.98	83.2	72.72	59.7
Total-Cu	31.69	27.12	4.57	16.8	32.36	26.31	6.05	22.9	46.81	28.85	17.96	62.3	28.58	34.7
Total-Ni	34.51	37.52	-3.01	-8.0	43.85	39.04	4.81	12.3	36.61	41.73	-5.12	-12.3	-3.32	-2.8
Total-Pb	52.56	52.56	0.00	0.0	89.60	38.80	50.80	130.9	638.51	37.24	601.27	1614.6	652.07	507.1
Total-Zn	105.02	110.42	-5.4	-4.9	143.05	98.25	44.80	45.6	329.77	110.20	219.57	199.2	258.97	81.2

is not included. The amount of nitrite (NO_2^-) is generally very small compared with the amount of NH_4^+ or NO_3^-. Application of high rates of NH_4^+ may result in NO_2^- accumulation in alkaline soils (Bremner 1965b).

When sewage wastewater is applied to a predominantly aerobic soil, the NH_4^+ in the sewage effluent will be converted to NO_3^- by the nitrification process. The applied N can be removed by plant uptake, denitrification, leaching, and ammonia (NH_3) volatilization. Denitrification is the most important process whereby the applied N in excess of plant uptake can be removed from the soil (Lance 1972). Long periods of flooding with sewage wastewater can stimulate the denitrification process in the soil. Stefanson (1973) showed that crops may increase N removal by stimulating denitrification in the root zone due to exudation of organic carbon and the creation of low oxygen levels. Nitrate, which was neither denitrified nor taken up by plants, will move down to the ground water. Thomas et al. (1974) found that a well operated overland flow system could achieve 90 percent N removal in the summer, but N removal may drop substantially in the winter.

The distribution of 2N KCl exchangeable NH_4^+-N, NO_3^--N, and NO_2^--N with soil depth in the sewage farm and the control area soil are shown in Figures 12, 13, and 14, respectively. In Angelo soils the NH_4^+-N concentration sampled from the sewage farm is less than that from the control area. In Rioconcho and Mereta soils the difference in NH_4^+-N concentration between the sewage farm soils and the control area soils varies with soil depth. There is an accumulation of NH_4^+-N in the upper 15 cm soil in Mereta soils of the sewage farm. There is no significant difference in NH_4^+-N concentration among three soil series and with soil depth (Table 33). Irrigation with sewage wastewater did not significantly change the NH_4^+-N concentration of Rioconcho, Mereta, and Angelo soils. There is a significant difference (at the 5 percent level) in NH_4^+-N concentration among soil cores sampled. The total exchangeable NH_4^+-N content at varying soil depth in the soil profile of Rioconcho, Angelo, and Mereta soils is shown in Tables 34, 35, and 36, respectively. Irrigation with wastewater increased by 120 and 4356 percent the total NH_4^+-N content in the soil profile of Rioconcho and Mereta soils (Table 37). However, in Angelo soils the total NH_4^+-N content on the soil profile decreased 81 percent. The overall average NH_4^+-N content of the top 20 cm soil column of these three soil series increased 224 percent. Reneau (1977) studied the changes in inorganic nitrogen compounds from septic tank effluent in a Virginia coastal plain soil. He found that the decrease in NH_4^+-N was due to the processes of adsorption and nitrification.

In both Rioconcho and Angelo soils the NO_2^- concentration of sewage farm soils is less than that of the control area soils (Figure 14). The NO_2^- concentration of Mereta sewage farm soils is greater than that of the control area. There are large amounts of NO_2^- in the 0-15 cm layer in the Mereta soils. There was no statistically significant difference in NO_2^- concentration among the three soil series, soil cores, or soil depths. No difference in NO_2^- concentration between the sewage farm soils and the control area soils is found (Table 33). The total exchangeable NO^--N content at varying soil depth in the soil profiles in Rioconcho, Angelo

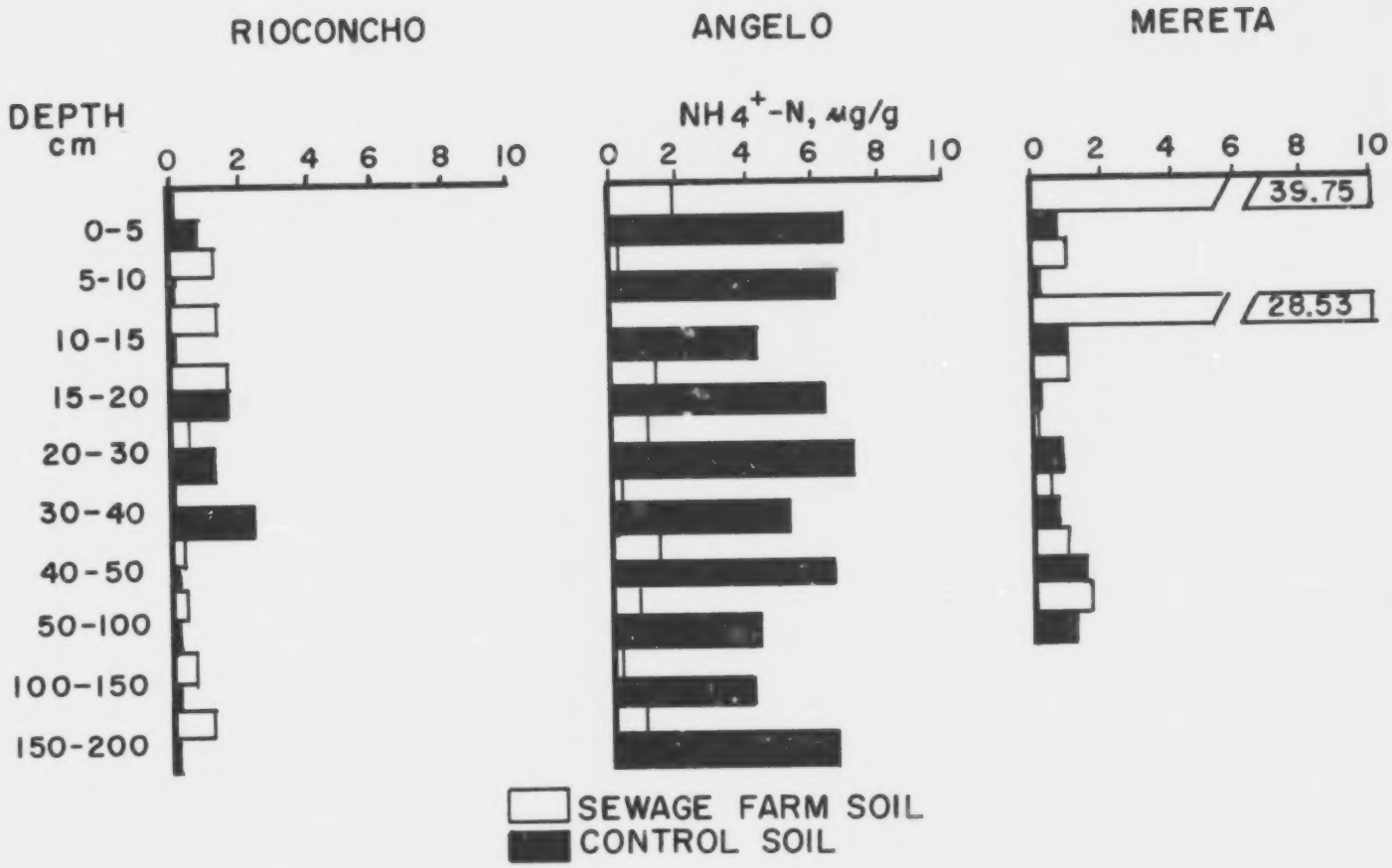


Figure 12. The effect of sewage effluent irrigation on exchangeable ammonium nitrogen content of the top 200 cm of soil from the sewage farm compared to the control area.

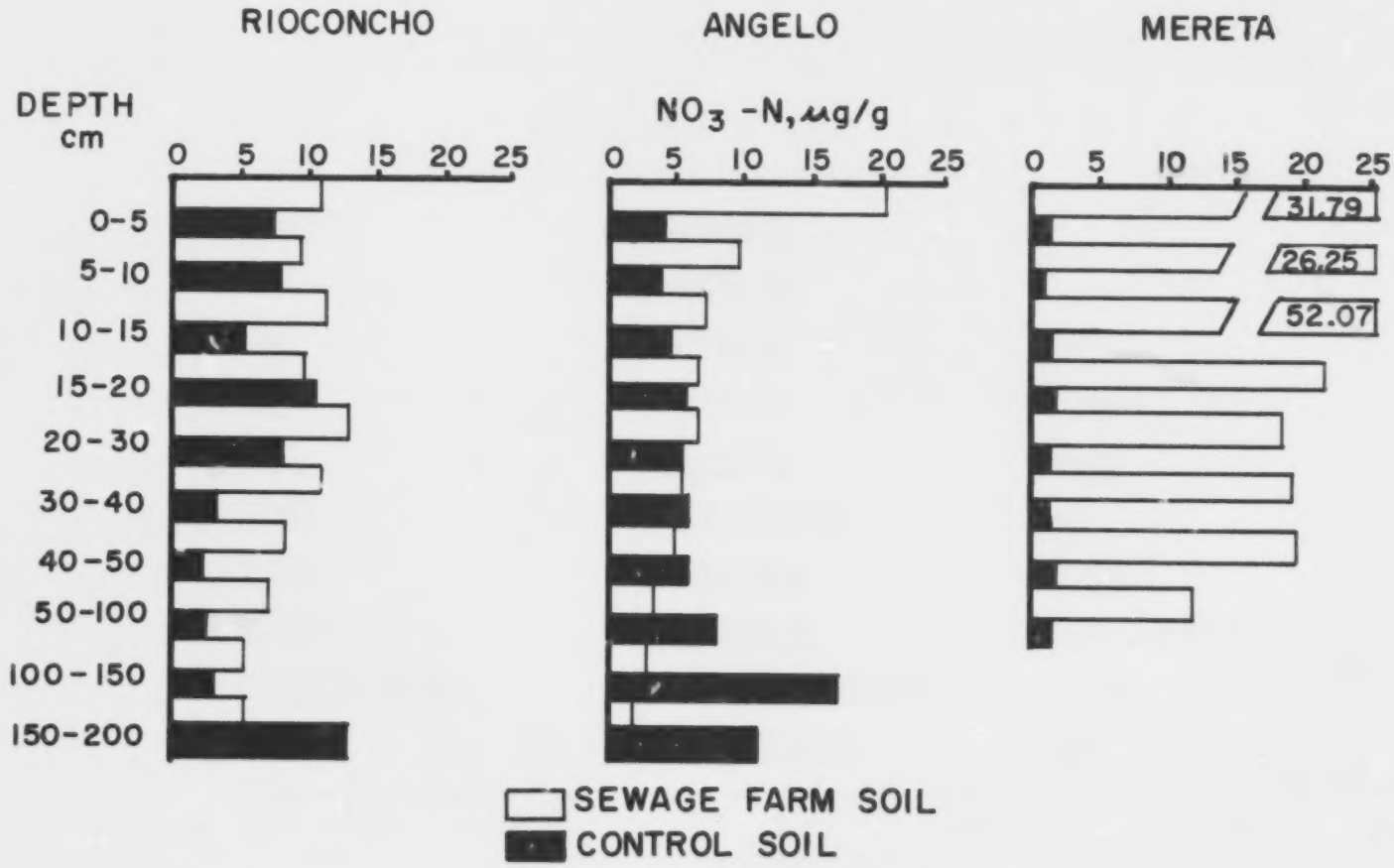


Figure 13. The effect of sewage effluent irrigation on exchangeable soil nitrate nitrogen content of the top 200 cm of soil from the sewage farm compared to the control area.

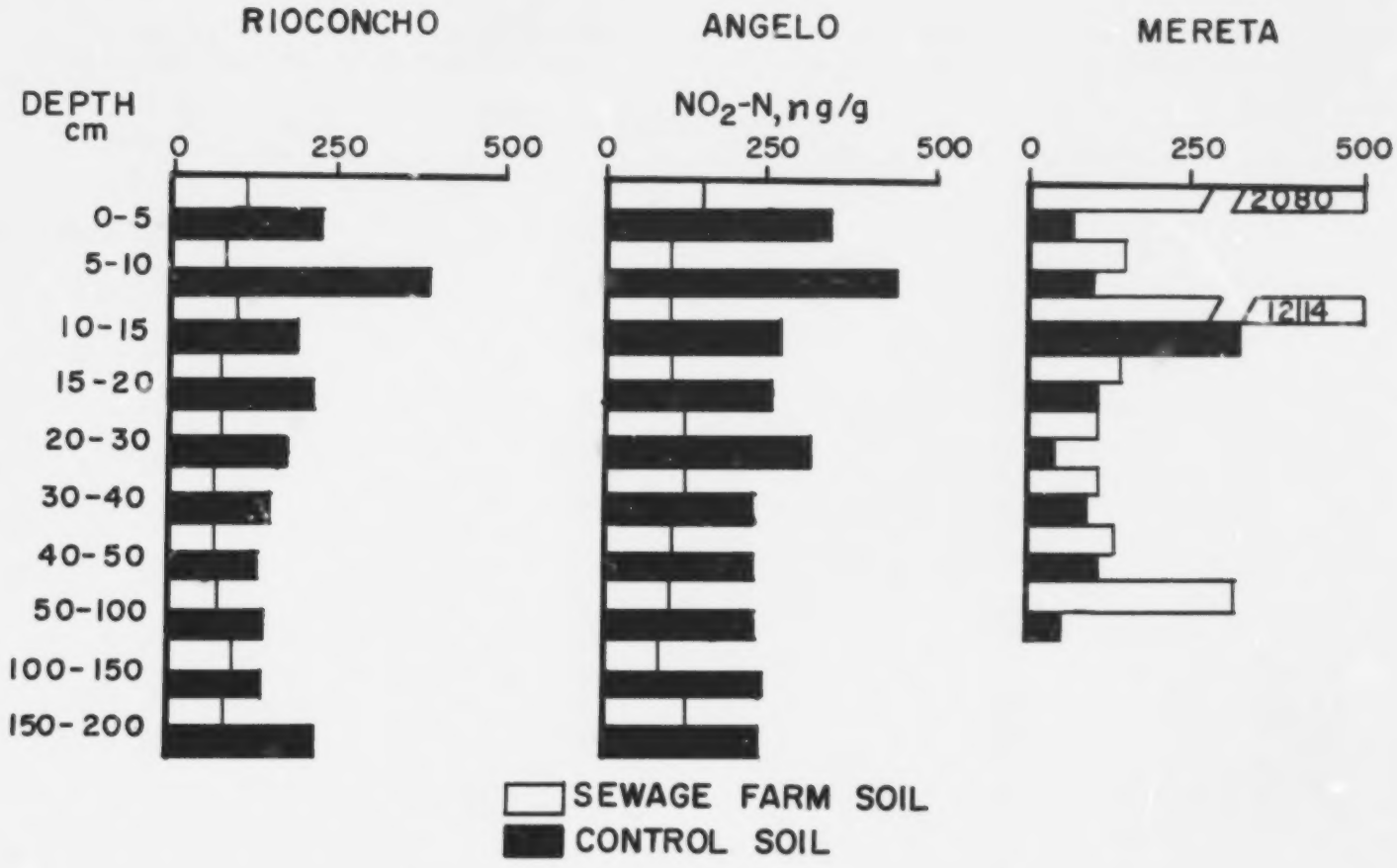


Figure 14. The effect of sewage effluent irrigation on exchangeable nitrite nitrogen content of the top 200 cm of soil from the sewage farm compared to the control area.

and Mereta soils is shown in Tables 34, 35, and 36, respectively. Irrigation with wastewater decreases the total NO_2^- content in the soil profile of Rioconcho and Angelo soils 63 and 53 percent, respectively (Table 37). In Mereta soils, an increase of 2139 percent in total NO_2^- content is found after wastewater irrigation. Irrigation with wastewater can change the NH_4^+-N or NO_2^--N content in a soil. However, the change may be positive or negative. There is an increase of 471 percent of NO_2^--N in the upper 20 cm soil column of all soils in the sewage farm after 18 years of wastewater irrigation.

The NO_3^- concentration of Mereta soils at the sewage farm is much greater than that of the control area soils. There is an accumulation of NO_3^- in the upper 50 cm soil in the Mereta soils after sewage irrigation. In Rioconcho and Angelo soils the difference in NO_3^--N concentration between the sewage farm soils and the control area soils varies with soil depth. Generally, the NO_3^- concentration of sewage farm soils decreases with increased soil depth. There is a significant difference (at the 1 percent level) in NO_3^- concentration among three soil series and among soil cores. No significant difference in NO_3-N concentration is found with varying soil depth. Irrigation with wastewater significantly (at the 1 percent level) changed the NO_3^- concentration of Rioconcho, Angelo, and Mereta soils (Table 33). Data presented in Tables 34, 35, and 36 show the total NO_3^--N content at varying soil depths in the soil profile of Rioconcho, Angelo, and Mereta soils, respectively. In Mereta soils the difference in total NO_3^- content of the upper 20 cm of soil between the sewage farm and the control area soils is 79.87 Kg/ha, an increase of 2096 percent based on the control area soils (Table 37). In Rioconcho soil the difference in total NO_3^- content in the upper 20 cm soil solum between the sewage farm and the control area is 7.12 Kg/ha, an increase of 36 percent. In Angelo soils an increase of 222 percent (22.2 Kg/ha) of total NO_3^- content in the upper 20 cm soil solum is found. Frere (1976) reported that soils cultivated for 100 years can have drainage waters with 5 to 10 ppm NO_3^--N. Kreitler (1975) found high NO_3^- concentration in the ground water in central West Texas. His study showed that the main source of NO_3^- in this region was the mineralization of organic soil N. Reneau (1977) observed NO_3^- accumulation in the plinthic horizon beginning at a distance of 1.27 m from the drainfield when septic tank effluent is applied.

Total Phosphorus

Total phosphate (P) concentration in soils ranges from 100 to 1300 ppm. Because of the low soil solution P (ranges from 0.01 to 1 ppm P) and high degree of fixation, soil P tends not to leach in soils. The applied P can be precipitated in soils as Fe^{+++}, Al^{+++}, Ca^{++}, $CO_3^=$, and OH^- phosphate compounds. In calcareous soils the calcium phosphate precipitate may be the main mechanism for P removal from wastewater (Lindsay and Moreno 1960).

Kao and Blanchar (1973) found that soil fertilized with P for 82 years had nearly double the total P content, but the ability of the soil to adsorb additional P was the same. No fertilizer P was found below 137 cm in the soil profile. Beek et al. (1977) studied distribution of soil P

in soil from a sewage farm in the Netherlands treated with domestic and industrial wastewaters. They showed that applied P accumulated in the top 50 cm layer of the soil.

The distribution of total P concentration with depth in the sewage farm soils and in the control area soils is shown in Figure 15. It is clear that the maximum total P concentration is found in the top 0-5 cm layer and decreases with increased soil depth in all three soil series in the sewage farm. No significant difference in total soil P with soil depth was found in the soil profiles of the control area. A comparison of the distribution of total soil P concentration with depth between the sewage farm and the control area indicates that applied P from sewage wastewaters had accumulated in the upper 150 cm in both the Rioconcho and Angelo soils and the upper 100 cm in Mereta soil. The application of sewage wastewater on land significantly increased (at the 1 percent level) the total P concentration in the soil profile of these three soil series (Table 33). There was a significant increase (at the 1 percent level) in total soil P concentration among three soil series, soil depth, and soil cores sampled.

Data in Tables 34, 35, and 36 show the total P content at varying soil depths in the soil profile in Rioconcho, Angelo, and Mereta soils, respectively. The average total soil P content in the whole soil profile of Rioconcho, Angelo, and Mereta soils is listed in Table 37. An increase of 44 to 243 percent of total soil P in the soil profile was found in these three soils after 18 years of sewage wastewater treatment.

Water Soluble Phosphorus

Water soluble P is a useful index of soil P availability for plant growth. Adsorption of P and growth of plants increase as water soluble P increases in soils low in P. Many studies have shown significant correlation between soluble soil water P and P uptake by plants (Olsen and Dean 1965).

The distribution of water soluble P content with depth in the sewage farm soils and in the control area soils is shown in Figure 16. The Rioconcho and Mereta soils inside the sewage farm have the highest water soluble P concentration in the top 0-5 cm layer. The P concentration then decreases with increasing soil depth. The highest water soluble P concentration is found in the 15-20 cm layer in Angelo soil, located inside the sewage farm. The water soluble P concentration is about the same in the whole soil profile of the Angelo and Mereta soils in the control area. Rioconcho soils from the control area have higher water soluble P concentration in the surface and decreases with increased soil depth.

Comparison of the distribution of water soluble P concentration with depth for the soils located in the sewage farm and control area indicates that there is an active pool of water soluble P in the soil profile inside the sewage farm. Irrigation with sewage wastewater significantly increased (at the 1 percent level) the water soluble P concentration in Rioconcho,

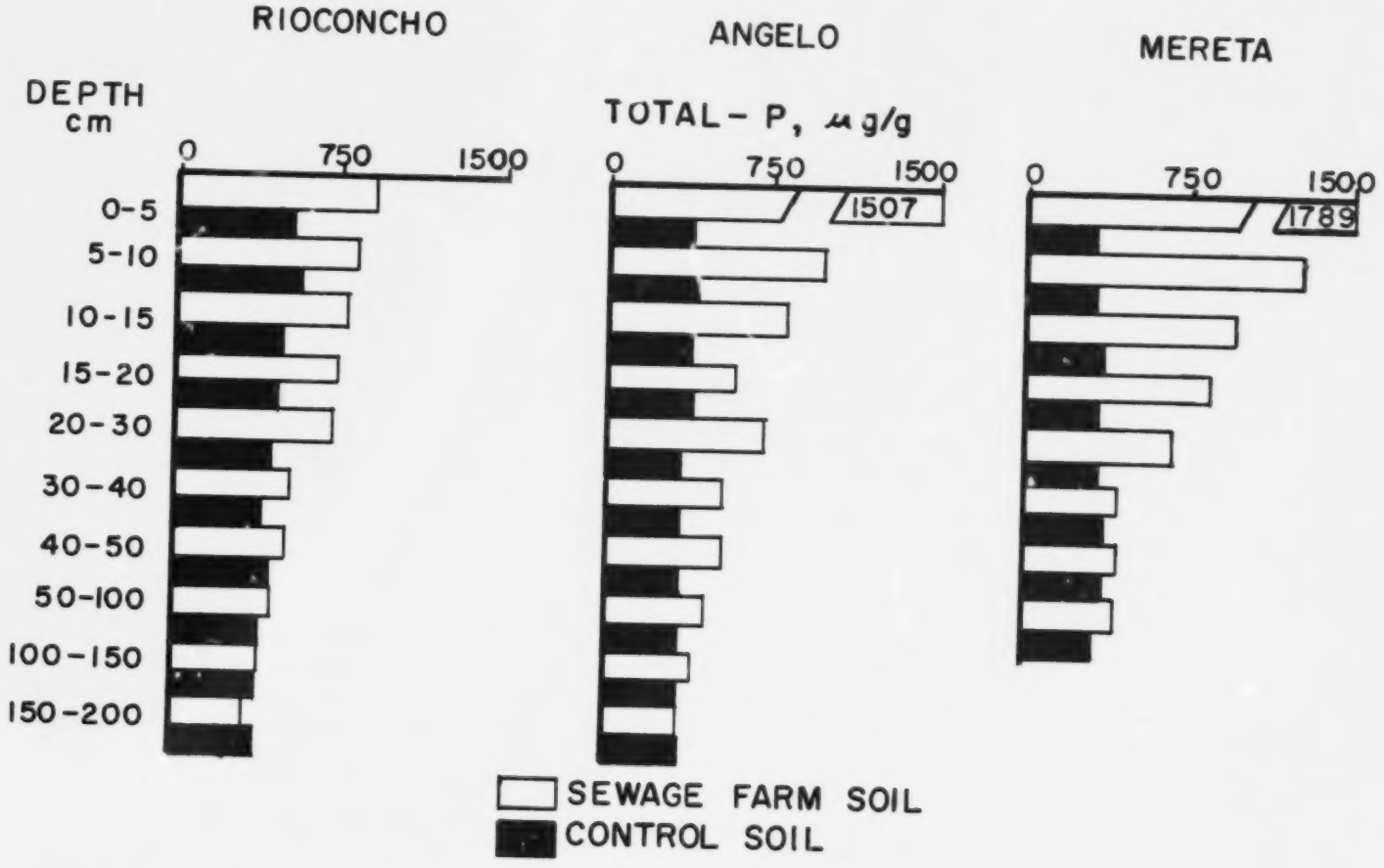


Figure 15. The effect of sewage effluent irrigation on total soil phosphorus content of the top 200 cm of soil from the sewage farm compared to control area.

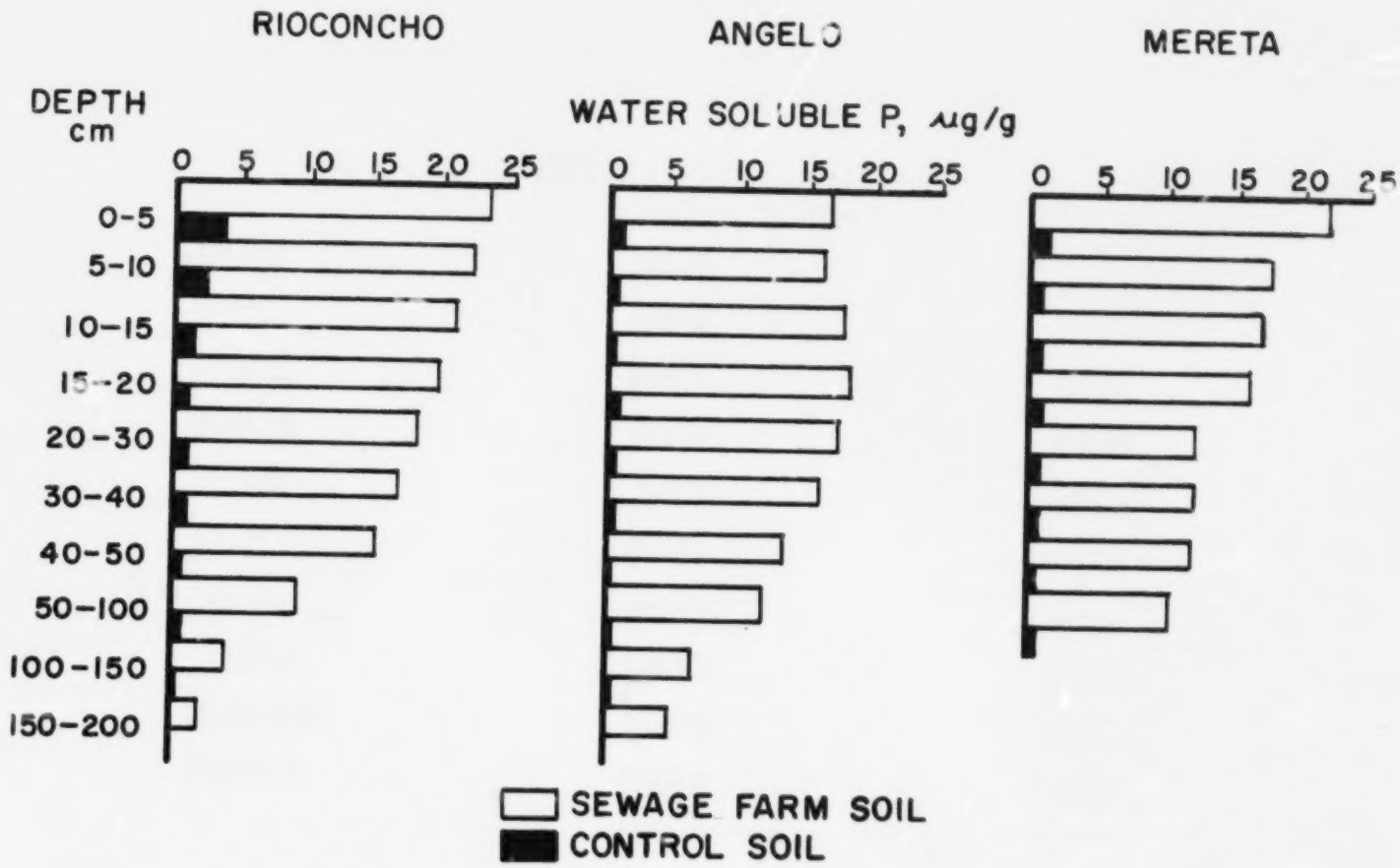


Figure 16. The effect of sewage effluent irrigation on water-soluble soil phosphorus content of 200 cm of soil taken from the sewage farm compared to the control area.

Angelo, and Mereta soils (Table 33). There is a significant difference (at the 1 percent level) in water soluble soil P concentration among soil depth and soil cores sampled.

The water soluble P content at varying soil depths in Rioconcho, Angelo, and Mereta soils is shown in Tables 34, 35, and 36, respectively. After 18 years of wastewater irrigation, the average total amount of water soluble P in the soil profile increased 936 percent in the Rioconcho soil, 3399 percent in the Angelo soil and 5276 percent in the Mereta soil. The water soluble P increased 1887 percent in the top 20 cm of all soils in the sewage farm after 18 years of wastewater irrigation. The water soluble P is greater than 15 µg/g P in the upper 20 cm layer of Rioconcho, Angelo, and Mereta soils (Figure 16). The percentage of water soluble P based on the total P content was also increased in all three soils in the sewage farm.

The distribution pattern with depth and the high concentrations of water soluble P in the soil profile indicate that the upper 40 cm layer of Angelo soil may have reached its maximum adsorption potential with regard to applied P in wastewater. The upper 20 cm layer has been saturated with respect to water soluble P, in Rioconcho and Mereta soils. It is clear that the upper 200 cm soil column has been affected to some degree by the applied P in wastewater. When the P fixation capacity of the soil is not sufficient to handle the desired volume of wastewater, the P-containing water will be filtered through the soil profile and reach the groundwater.

Total Heavy Metals

Heavy metals can influence environmental quality by their potential hazard and toxicity to man and other living organisms. Heavy metals in soils and plants are the major link in the heavy metal cycle in the food chain. One of the unknown factors of land application of wastewater is the contamination and accumulation of heavy metals in the soil, especially in regard to long-term effects. Lisk (1972) warned that using sewage wastes for plant fertilizer might be a dangerous practice. He pointed out that some edible plants may concentrate toxic heavy metals present in wastes to a level which would not harm plants but which could be toxic to animals. Keefer and Estepp (1971) found most of the labeled Zn-65 applied to soils became acid-soluble and/or fixed on the clays. Fuller et al. (1976) reported that the municipal landfill leachate was relatively low in heavy metals and that those present did not migrate through the soils in significant quantities. They found that all soils examined did not release heavy metals at the same rate. A study at the sewage farm in Melbourne, Australia showed that large amounts of metals have accumulated during 70 years of application of raw and settled sewage (Bouwer and Chaney 1976). It is clear that soil-plant systems play an important role in the renovation of wastewater.

Cadmium

Cadmium (Cd) levels in non-polluted soil are usually below 1 ppm (Haan and Zwerman 1976). Buchaver (1973) found 1,700 ppm Cd in topsoil sampled near a zinc smelter. The Cd concentration in phosphate fertilizers ranges from 1-2 ppm for tertiary calcium phosphate to 50-170 ppm for superphosphate. Miller et al. (1976) investigated the relationship between uptake of Cd by soybean and soil available P and found that Cd accumulation increased with increasing available soil P. Williams and David (1976) reported that at least 80 percent of the Cd impurities in P fertilizers applied could be accounted for in the cultivated layers of soil. The sources of soil Cd are varied but may come from the application of wastes and P fertilizer, fallout, precipitation, decomposition of plant residues and microorganisms, and weathering of soil parent materials.

The distribution of total Cd concentration with soil depth in the sewage farm soils and the control area soils is shown in Figure 17. There is a highly significant difference in total soil Cd concentration among the three soil series, among soil cores sampled, and at different soil depths (Table 33). However, comparison of the total Cd concentration of soils in the sewage farm and the control area indicates no significant change in total soil Cd concentration after 18 years of wastewater irrigation. The average total amount of Cd content in the upper 20 cm soil solum of the sewage farm changes -19.3 percent in Rioconcho soils, -4.5 percent in Angelo soils, and +43.2 percent in Mereta soils (Table 37). This amounts to a 3.1 percent increase of all top 20 cm soils of the sewage farm after 18 years of wastewater treatment.

Chromium

Chromium (Cr) has been considered nonessential for plant growth; whereas it is essential to animals and man. Chromium plays an important role in carbohydrate metabolism and prevention of diabetes. Chromium reaches the soil through sanitary landfills, urban air, snow melting salts, industrial and sewage wastes, and weathering of soil parent material. The Cr content of most soils is usually limited to trace amounts. In soils treated with sewage sludges the Cr concentration can reach up to 50,000 ppm (Walsh et al. 1976). Dowdy and Larson (1975) found that Cr from sewage sludges is less available to barley plants grown in alkaline soils compared to those grown in acid soils. Lindsay (1973) reported that Cr is generally oxidized from Cr(II) or reduced from Cr(VI) to Cr(III) and precipitated as an insoluble hydroxide. Bartlett and Kimble (1976) showed that the presence of soil organic matter brought about spontaneous reduction of Cr(VI) to Cr (III) even at pH's above neutrality.

The distribution of total Cr with soil depth in the sewage farm and the control area soils is shown in Figure 18. In Mereta soils sampled at the sewage farm, a small amount of Cr (32.12 Kg/ha) was accumulated in the top 0-5 cm (Table 36). There is a significant difference (at the 5 percent level) in total Cr concentration between the sewage farm soils and the control area soils. A significant difference (at the 10 percent

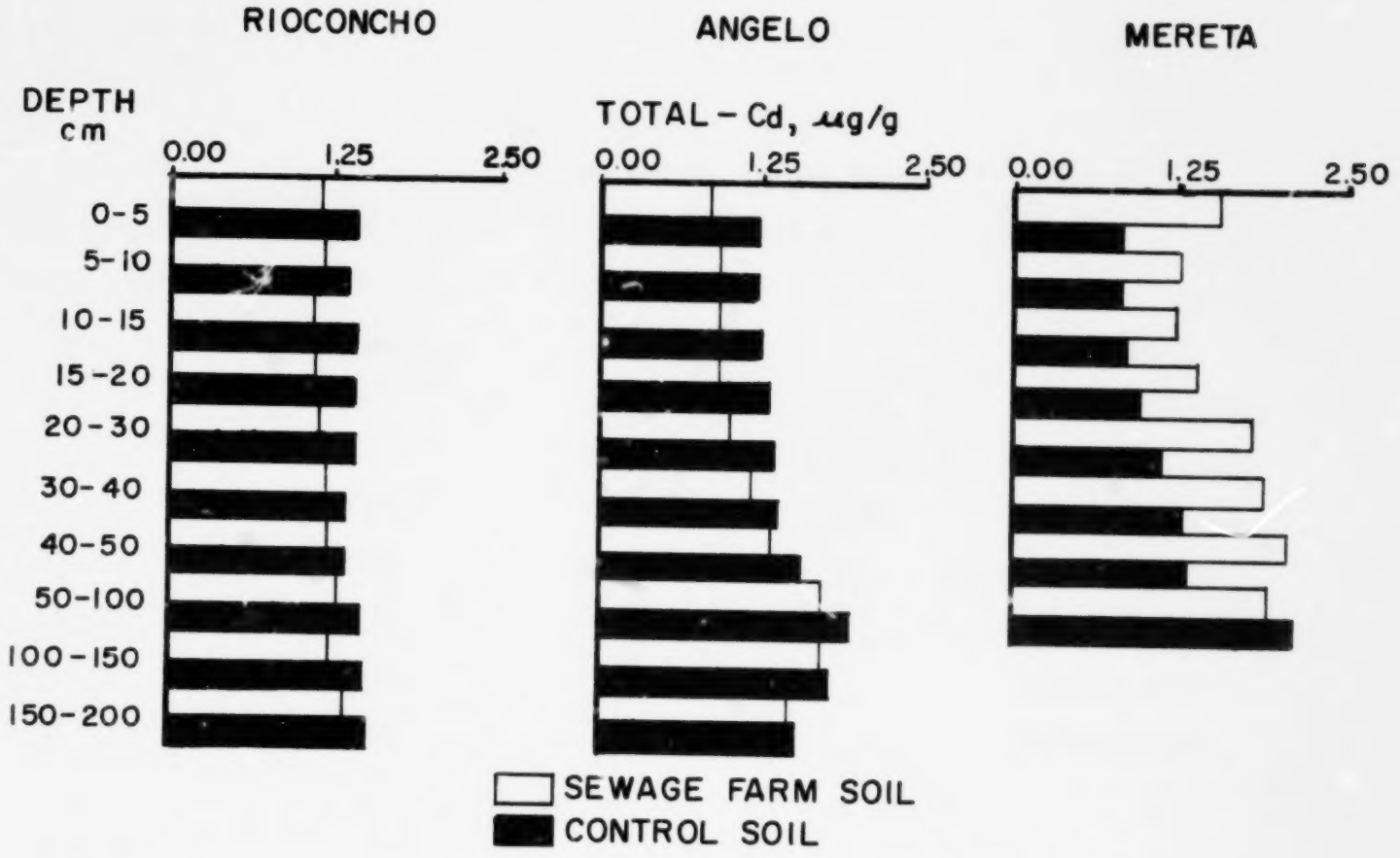


Figure 17. The effect of sewage effluent irrigation on total soil cadmium content of 200 cm of soil taken from the sewage farm compared to the control area.

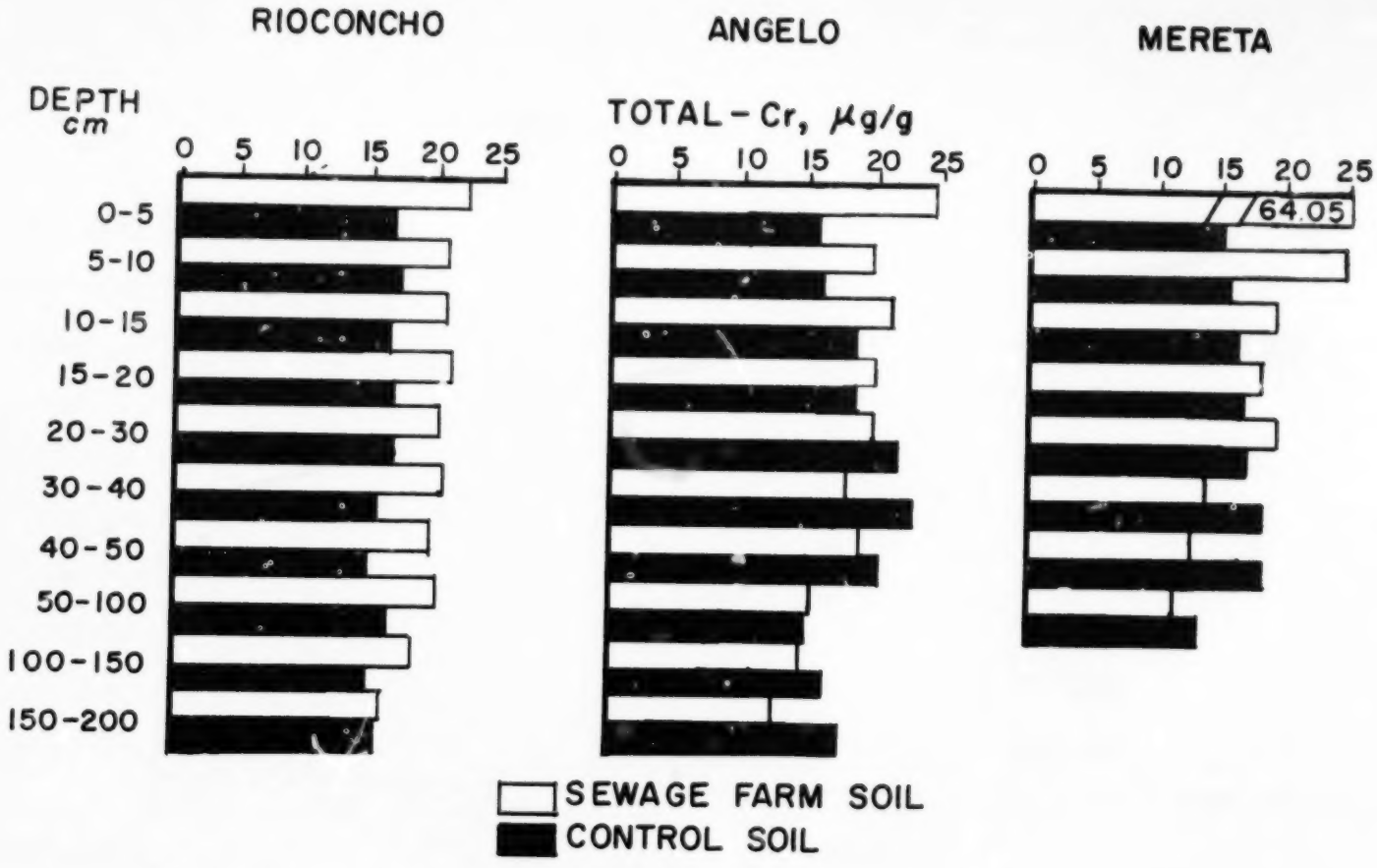


Figure 18. The effect of sewage effluent irrigation on total soil chromium content of 200 cm of soil taken from the sewage farm compared to the control area.

level) in total Cr concentration among soil cores sampled and among soil depth was found (Table 33). The average total Cr content in the soil profile of the sewage farm changed 30.1 percent in Rioconcho soil, 65.7 percent in Angelo soil and 83.2 percent in Mereta soil after 18 years of sewage wastewater irrigation (Table 37). The average increase of total Cr content of all soils in the top 20 cm was 59.7 percent.

Copper

Copper (Cu) is essential to plant growth and has a normal concentration in plant tissue ranging from 5 to 20 ppm (Walsh et al. 1976). The concentration of Cu in soils ranges from 2 to 100 ppm with an average of 20 ppm (Haan and [illegible]an 1976). In neutral and alkaline soils Cu exists in soil solution as the Cu^{+++}, and $Cu(OH)^{+}$ ions. The Cu in soils may originate from fertilizer, manure, mine effluents, industrial and sewage wastes, and soil parent materials. Copper sulfate has been used as either a fungicide for fruit crops and potatoes or as an additive in swine and poultry feed. The mobility of Cu in soils is low and Cu tends to accumulate in the topsoil. Jenne (1968) postulated that the hydrous oxides of Mn and Fe control the concentration of Cu, Ni, and Zn in soils and water. Stevenson (1977) studied the nature of the binding of divalent metal ions by soil humic acid. He showed the stability constant of metals in soils followed the order Cu>Pb>>Cd>Zn.

The distribution of total Cu with soil depth in the sewage farm soils and the control area soils is shown in Figure 19. In Mereta soils in the sewage farm, an accumulation of Cu in the 0-5 cm of top soil was observed. This is a significant increase (at the 10 percent level) in total Cu concentration between the sewage farm soils and the control area soils (Table 33). Irrigation with wastewater on the sewage farm increased the average total Cu content in the upper 20 cm soil solum in Rioconcho soils, Angelo soils, and Mereta soils by 16.8, 22.9, and 62.3 percent, respectively. This amounts to an average of 34.7 percent increase of total Cu content in these three soil series (Table 37).

Lead

Lead (Pb) is a biologically nonessential heavy metal. The total Pb concentration of soils ranges from 2 to 200 ppm with an average of about 10 ppm (Allaway 1968). The sources of Pb in soils include pesticides, insecticides, fertilizer impurities, mining and smelting operations, engine exhausts, and industrial and sewage wastes. One of the potential hazards associated with Pb contamination of soil is animal ingestion of plants with abnormally high concentrations of Pb, which may be toxic to the animal. Lagerwerff and Specht (1970) reported that Pb concentrations reached as high as 24,000 ppm in soils located directly along a roadside in the Los Angeles metropolitan area. Singer and Hanson (1969) studied the Pb accumulation in soils near highways and found that $PbCO_3$, $Pb_3(PO_4)_2$, and $PbSO_4$ were the insoluble Pb compounds formed in the soil. Walsh et al. (1976) suggested that in calcareous soils in the arid and semi-arid region, lead carbonate may form and the calcareous soil would then act as a sink for applied Pb.

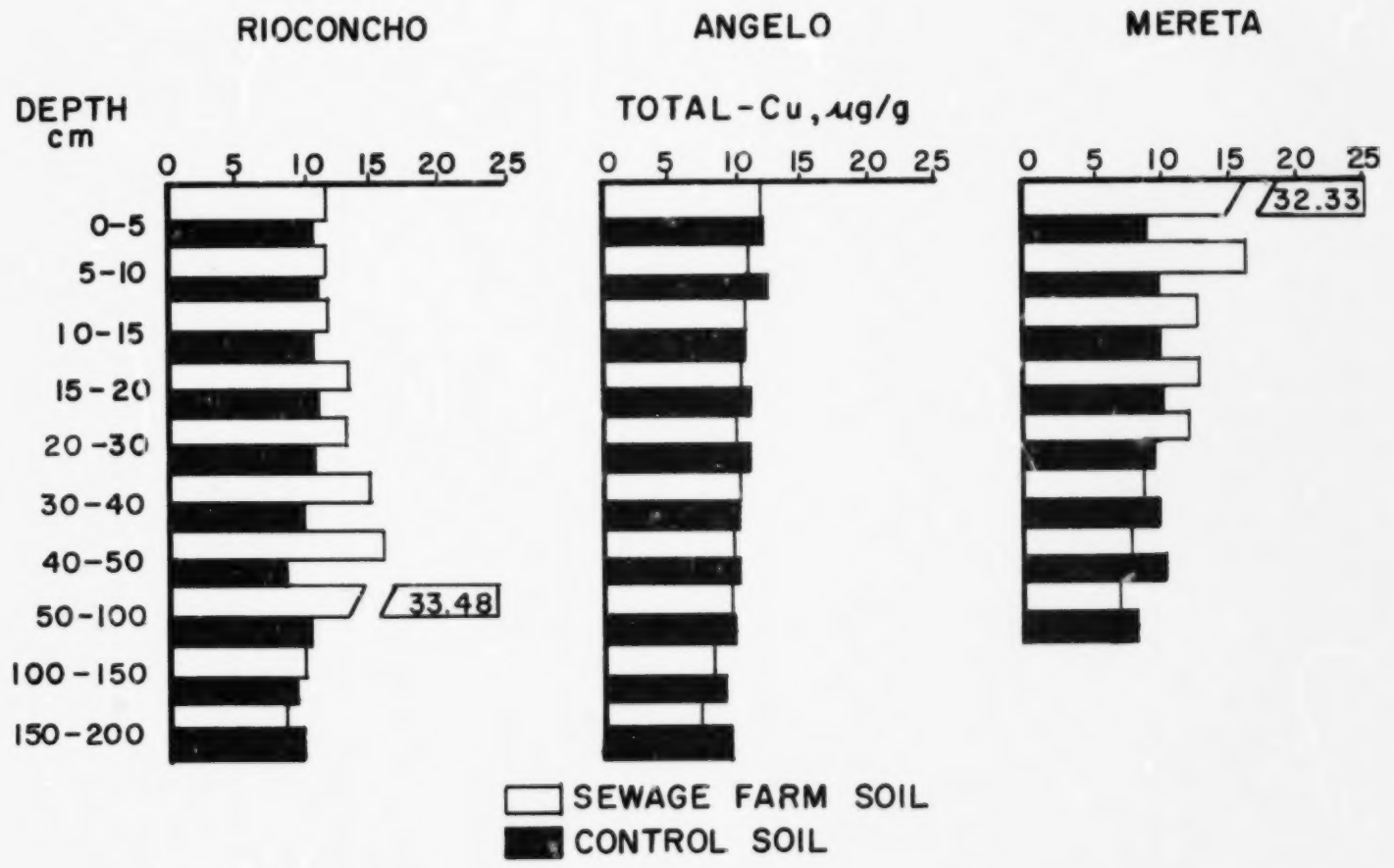


Figure 19. The effect of sewage effluent irrigation on total soil copper content of the top 200 cm of soil taken from the sewage farm compared to the control area.

The distribution of total Pb with soil depth in the sewage farm and the control area is shown in Figure 20. An accumulation of total Pb in the upper 50 cm of soil in Mereta soils at the sewage farm was observed. There is a significant difference at the 1 percent level for total Pb concentration among three soil series and among soil cores sampled (Table 33). Irrigation of wastewater on the sewage farm significantly increased (at the 1 percent level) the total lead concentration in the three soil series. The average increase in total Pb content in soil profiles of the sewage farm are 0.0, 130.9 and 1614.6 percent in Rioconcho, Angelo, and Mereta soils, respectively (Table 37). The average increase of total Pb content of these three soil series is 507.1 percent after 18 years of wastewater irrigation.

Nickel

To date nickel (Ni) has no essential function in plant growth. It is readily absorbed by plants. The total Ni concentration of soil may vary from 5-500 ppm, with mean values commonly around 40 ppm (Allaway 1968). Most of the Ni in soils comes from weathering products of basic rocks, impurities in superphosphate fertilizer, automobile exhausts, and industrial and sewage wastes. Nickel is considered 8 times as toxic as Zn to plant growth in the calculation of the "Zn equivalent factor" (Chumbley 1971). The U. S. Environmental Protection Agency suggests that Ni is 4 times as toxic to plants as Zn in the calculation of their "metal equivalent". Hinesly et al. (1972) found 42 to 56 percent of the Ni applied as sewage sludge is retained in the surface 15 cm of soil. Anderson and Nilsson (1972) showed a 140 percent recovery of Ni in the surface 20 cm of soil treated with 84 metric tons of sewage sludge over a period of 12 years.

The distribution of total Ni with soil depth in the sewage farm soils and the control area soils is shown in Figure 21. Generally, the total Ni concentration increased with increased soil depth, and reached a maximum at the 50-100 cm depth. There is a significant difference (at the 1 percent level) in total Ni concentration among three soil series, among soil cores sampled, among soil depth, and between the sewage farm soils and the control area soils (Table 33). Irrigation of sewage wastewater over a period of 18 years increased the average total Ni content in the upper 20 cm Angelo soil solum by 12.3 percent (Table 37). In Rioconcho soils and Mereta soils a decrease of 8.0 to 12.3 percent of average total Ni content in the upper 20 cm soil solum was observed. This amounts to a decrease of 2.8 percent of total Ni content of these tnree soil series.

Zinc

Zinc (Zn) is an essential element for both plants and animals. It is an important component of a number of enzyme systems. Zinc reaches the soils in various chemicals and wastes. The total Zn concentration of soils under normal conditions ranges from 10-300 ppm, with an average value of 50 ppm (Allaway 1968). Lindsay (1973) showed that the predominant Zn series in soils below pH 7.7 is Zn^{++} and at higher pH values is $Zn(OH)^{+}$. Toxic Zn symptoms usually start at about 400 ppm and up for most plant species. If the Zn content of the animal diet exceeds about 1000 ppm, Zn toxicity will occur in animals (Haan and Zwerman 1976). Chaney (1973)

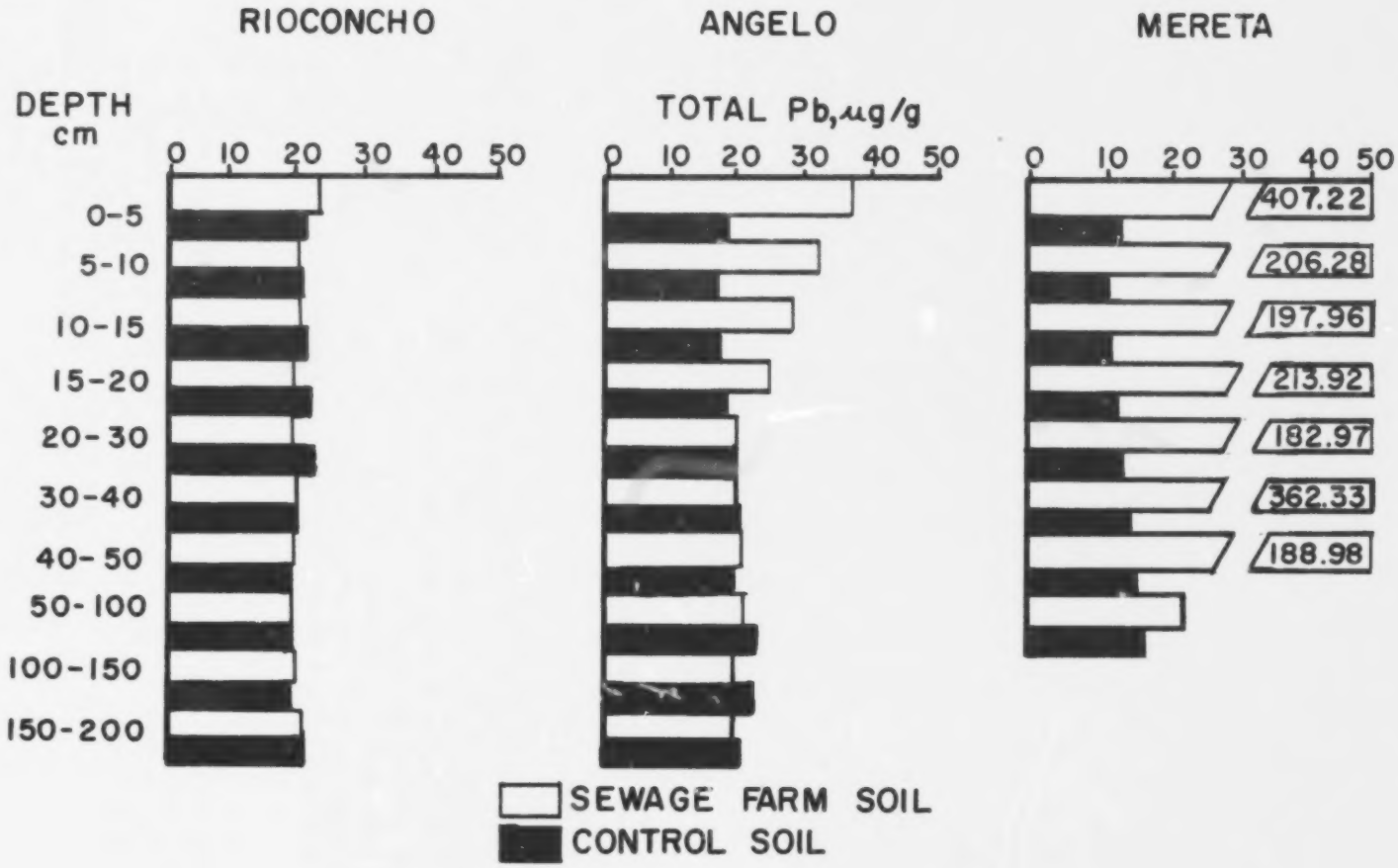


Figure 20. The effect of sewage effluent irrigation on total soil lead content of the top 200 cm of soil taken from the sewage farm compared to the control area.

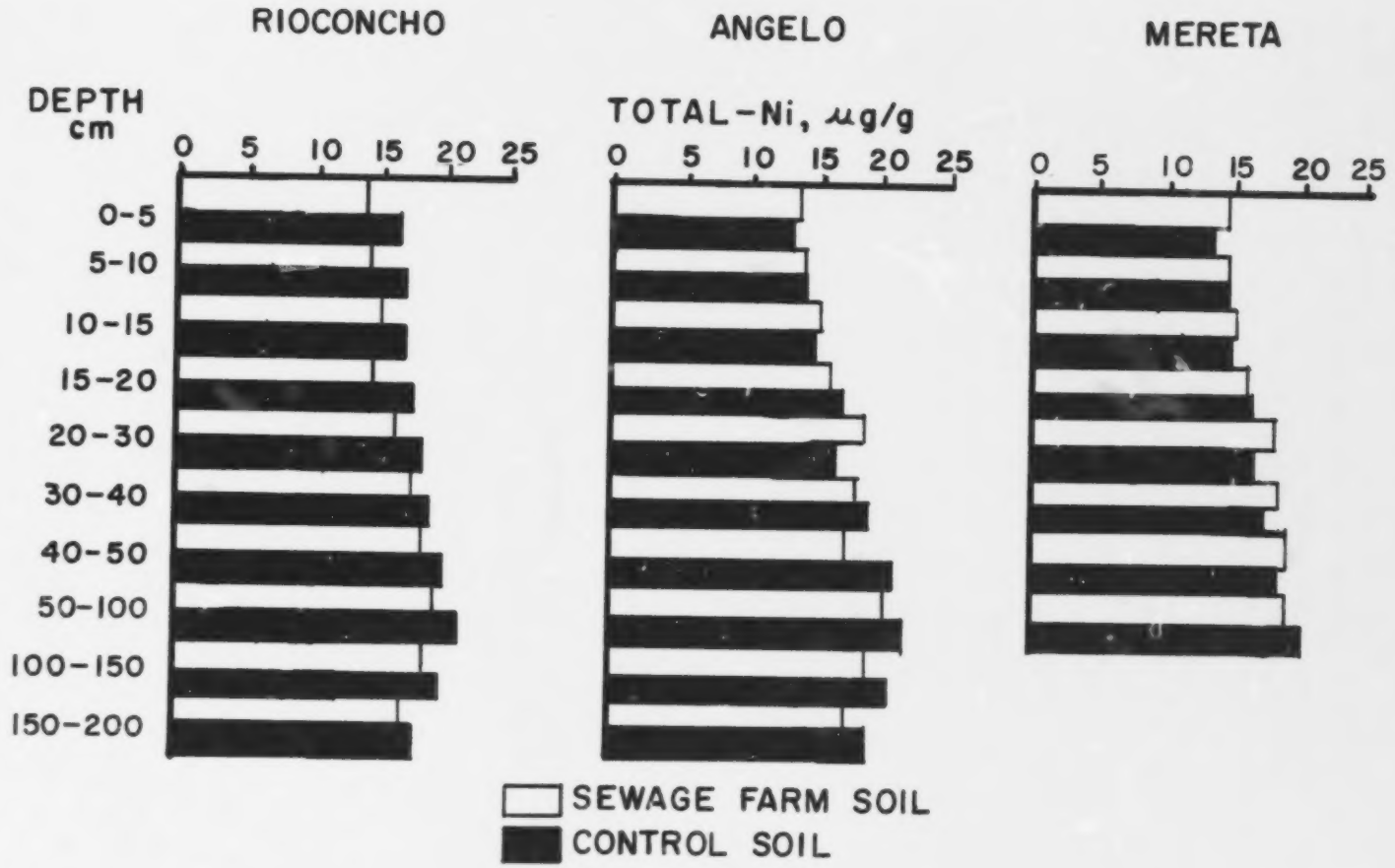


Figure 21. The effect of sewage effluent irrigation on total soil nickel content of the top 200 cm of soil taken from the sewage farm compared to the control area.

recommended that the toxic metal addition should not exceed Zn equivalent levels equal to 5 percent of the CEC at pH≤6.5. Decreasing the soil pH will increase the total Zn concentration and its availability to plants. Cunningham (1975) found that enhancement of soil total Zn to 1,300 ppm by sludge treatment would cause plant Zn concentrations in excess of 900 ppm and result in severe reduction of yield.

The distribution of total Zn concentration with soil depth in the sewage farm soils and the control area soils is shown in Figure 22. There is an accumulation of total Zn in the upper 10 cm soil in Mereta soil series. Irrigation with sewage wastewater does not change the Zn concentration of soils in the sewage farm (Table 33). There is a significant difference in total Zn concentration among the three soil series, among soil cores sampled, and among soil depths. The differences in total Zn content between the sewage farm and the control area in the upper 20 cm soil profile of Rioconcho, Angelo, and Mereta soils are -4.9, +45.6, and +199.2 percent, respectively. Irrigation of wastewater increases 81.2 percent of total Zn content in the top 20 cm soil profile of these soil series of the sewage farm.

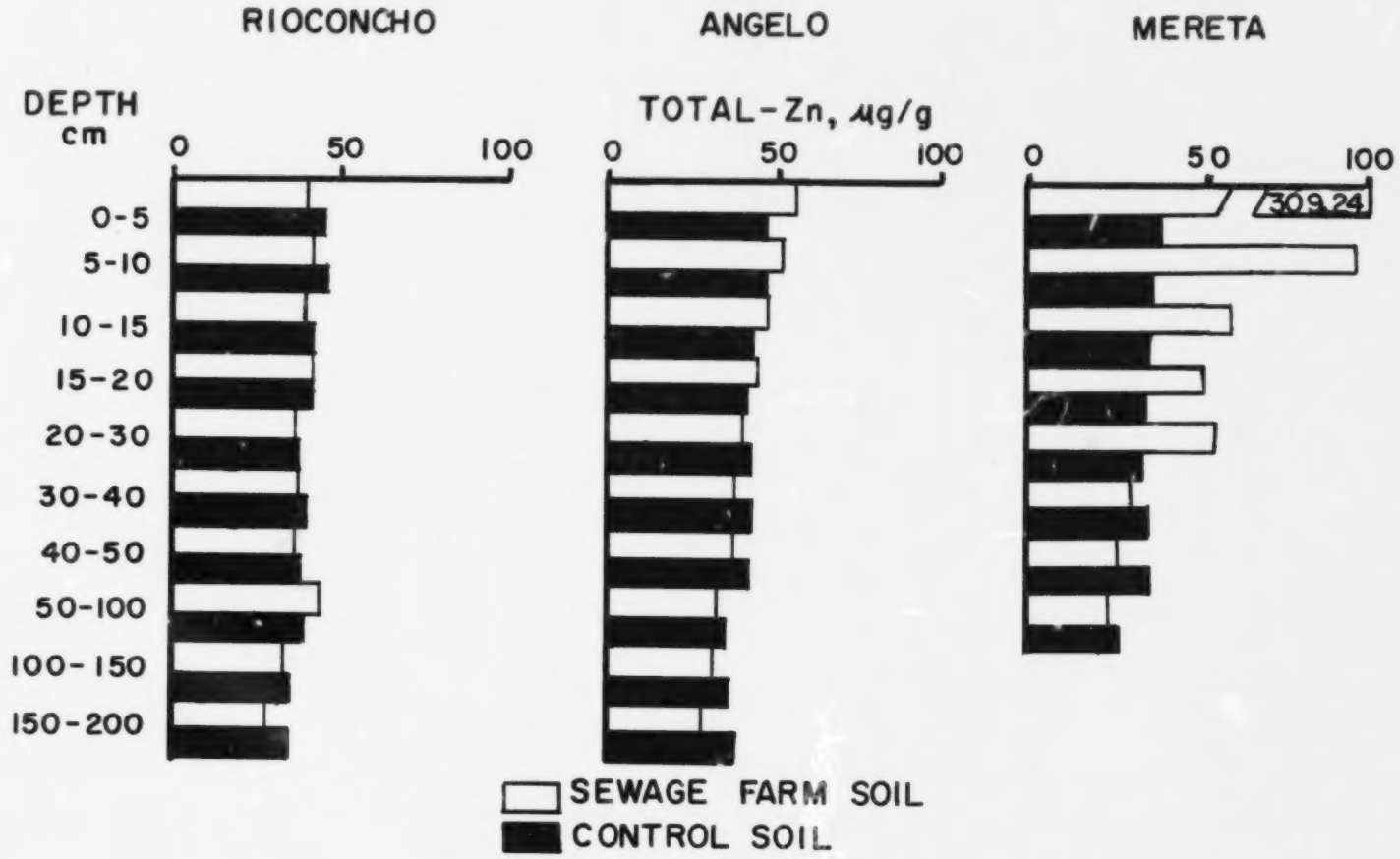


Figure 22. The effect of sewage effluent irrigation on total soil zinc content of the top 200 cm of soil taken from the sewage farm compared to the control area.

SECTION 7

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